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APPLICATION NUMBER: ***60/461,883***
FILING DATE: ***April 10, 2003***
RELATED PCT APPLICATION NUMBER: ***PCT/US04/10236***

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04-11-03 60461883 .041103

04/10/03 1051 U.S. PTO

PTO/SB/16 (10-01)
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. ET 74 74070 3US

JC857 U.S. PTO 60/461883

INVENTOR(S)

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TITLE OF THE INVENTION (500 characters max)

Comprehensive motion control using electromagnetic forces: magnetic, Induction, or hysteresis, and application to apparatus.

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ENCLOSED APPLICATION PARTS ***(check all that apply)***

☑ Specification *Number of Pages* 98 (93 to 98 omitted) ☐ CD(s), Number ______

☐ Drawing(s) *Number of Sheets* Included in spec ☐ Other (specify) ______

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

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Respectfully submitted,

SIGNATURE G. N. Srinivasa Prasanna

Date April 10, 2003

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(if appropriate)
Docket Number: ______

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

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Full Colour originals will be furnished on request. G.N. Srinivasa Prasanna April 10/2003

CROSS-REFERENCE TO RELATED APPLICATIONS:
None

STATEMENT OF FEDERALLY SPONSORED R&D:
Not federally sponsored.

BACKGROUND OF THE INVENTION:

This invention pertains to the use of electromagnetic force/torque, using possibly induction and hysteresis, for ***control of motion in unpowered (human powered) apparatus, and electric motor/other prime mover driven apparatus. The apparatus may in general, incorporate complex mechanisms***. By control of motion we mean control of ***speed of operation of the apparatus (speed), time taken by the apparatus to reach one or more significant positions (timing), and force/torques exerted on one or more sources of power to the apparatus, one or more external loads, or internally between various pieces of the apparatus. The control of motion enables, of course, control of position of the apparatus. In certain embodiments of the invention, one or more positions of the apparatus may be stable low energy states to which the apparatus preferentially moves, which we shall refer to as rest states***. In particular, we describe ***modifications of electric motors, induction clutches and brakes, and electromagnetic actuators***, yielding new devices, which can be used for controlling motion of a large variety of apparatus. We also describe ***new application of our devices in existing apparatus, as well as new kinds of apparatus***, yielding hitherto unrealised benefits.

In all that follows, we shall generally discuss electromagnetic induction based techniques, but the techniques can be directly translated into hysteresis based techniques, as well as techniques based on magnetic attraction/repulsion, and are additionally stated

by implication of this statement here. Where required, we shall mention differences (see Section A[4], and A[5]).

The main objective of the present invention is to extend the domain of electric motor speed control (and general motion control), traditionally characterized by electronic techniques, to small apparatus like bubble vibration toys, paper dispensers, well pulleys, toothbrushes, display turntables, rotating lollipops, very low cost timing CAMs, toy racing cars, drawers, hinged objects, etc. ***These apparatus will be hereafter collectively referred to as SAs***. These apparatus are either unpowered (i.e. human powered), or typically run on one or two AA/AAA batteries, generating a maximum of 3V initially, and less after a little use. This voltage is too low for cost-*effective electronic control of motion*. Indeed, at these voltages (definitely with 1.5V), even simple resistive motor speed control techniques can become ineffective. The object of the present invention is to achieve such control, possibly in a user-customizable fashion, at low cost. Primarily but not exclusively, physical motion of appropriately shaped magnetic flux producing devices, and appropriately shaped interacting devices is used for the control. ***While the invention is primarily targeted at low cost mass-market applications, this does not limit its use in other contexts, e.g. in high reliability environments due to simplicity of design, very high-performance apparatus due to easy modification of apparatus static and dynamic behaviour to simplify control, etc.***

Prior art in motion control, either for apparatus driven by traditional rotating motors, linear motors, or even non-electrical prime movers like internal/external combustion engines (hereafter referred to as IC/EC engines), have relied primarily on a combination of [1][2][3][6][8][9]

(1) Power Control (referred to as PC): ***The power generated at one or more inputs to the apparatus is modulated as desired***. Examples include pulse-width modulation/resistive control for motors, and/or gasoline/fuel injection control for IC/EC engines. These methods may or may not involve closed loop feedback, using either back-emf sensing techniques, speed tachometers, or a combination of the two.

(2) Power Transmission Control (referred to as PTC): ***<u>The power transmitted to the apparatus is modulated as required</u>***. Clutches (friction, hydraulic, eddy-current/hysteresis) are examples. The amount of power transmitted to the load can be modulated within limits.

(3) Load Control (referred to as LC): ***<u>The total resistive force presented by the apparatus is modulated as desired</u>***. Friction/induction brakes have been primarily used for completely stopping, or aiding the stopping process of a prime mover, but typically have not been used for controlling speed, during normal running of the prime mover. The primary reason being that these are dissipative methods, and friction brakes are prone to stick-slip.

These techniques are generally applicable. They can be applied to apparatus having no preferred position (no rest-state), as well as apparatus that have preferred positions (rest-states). Mechanical ratcheting devices, electromagnetic relays, latches, actuators, etc are examples, of apparatus having rest-states.

Existing implementations of these techniques are in general too expensive and unsuited (due to power requirements, etc), for the targeted applications. The invention offers new implementations of PC, PTC, and LC overcoming these limitations. Additionally, our invention offers the ability to configure arbitrary rest-states of general mechanisms. *<u>Even in applications where the existing techniques are suitable, our invention can offer benefits in terms of simplicity of operation, high reliability, fail-safeness, etc.</u>*

Prior art in Power Control, mainly deals with much larger apparatus. In US Patent, 6,380,709, Nishimura, et al. teach an improved means of driving a motor, using controlled switching of power transistors, to obtain better rotation characteristics. In US Patent, 6359,410, Randolph, et. al. teach the use of resistive sensing to better control the maximum current applied to the motor. In US Patent 5349,276. Mezzatesta. et al. utilize an electronic tachometer to monitor motor speed accurately, and feed this information to a control system for controlling speed reliably, in a safe-operating regime. In US Patent 6344,721 and 6340,873, Seki et al. describe a semiconductor integrated circuit for brushless motor drive control. None of this art teaches how to control motion in SAs.

Prior art in Power Transmission Control is also primarily targeted at industrial applications. In US Patent 6157,147 and 6346784, Lin et al, teach the use of an eddy-current clutch to transmit power, after suitable speed translation. In US Patent 5586636, Linnig, et al teach the use of an eddy-current clutch in conjunction with a friction clutch, to transmit power for the fan wheel of an IC/EC engine. None of these patents teach how to controllably transmit power in SAs. Even when certain embodiments of the invention can be classified as electromagnetic clutches (eddy-current and/or hysteresis clutches), the invention distinguishes itself from the state-of-art in

(a) Novel geometry of the clutch
(b) Novel very low cost programmability of transmitted force/torque.
(c) Application to apparatus, which so far have not used them, due primarily to very low cost design.

Prior art in Load control (LC), includes eddy-current and hysteresis brakes. Gersemsky, et al, in US patent 6460828, describe an eddy current brake for a hoist, where a set of permanent magnets is selectively positioned to generate variable eddy current force in an induction member, thus braking the hoist. The magnets move radially outwards, to increase the braking force, and reduce the torque. However, in this invention, the use of the eddy-current brake to provide a constant speed (not to stop the device) is not described. Also, the method is applicable to large apparatus like cranes, and it is not indicated how to apply the invention in SAs. In US patent 6062, 350, the use of conductors of varying thickness, conductivity, etc has been mentioned for braking an amusement car on a track. In US patent 6185,373, a camera with induction brake is described. Here the device is used to apply braking force, to stop the motion of the camera shutter, under control of the control circuitry. Our invention differs from this that the control may be, in one embodiment, just by the placement of conductive strips (or other conductive members), and permanent magnets at appropriate positions. Also, we use the mechanism for detailed control of motion timing in mechanisms, and arbitrary timing waveforms can be generated. Again, these patents do not describe applicability of these devices to SAs.

Even when, certain embodiments of the invention are classifiable as induction brakes, the invention differentiates itself from the state-of-art in

(a) Duration of application of the induction force/torque, which is typically held on during the normal operation of the apparatus, and changing the magnitude of the induction force/torque changes the apparatus/prime mover speed.
(b) The new methods of generating the controllable induction force/torque.
(c) Utilization of these new methods to change the speed/timing/forces/torques, in a single cycle of apparatus operation, possibly in a programmable fashion.
(d) Exploitation of the property that the induction force is velocity dependent, to provide automatic speed control feedback.
(e) Application to apparatus, which so far have not used the invention, due primarily to the very low cost design.

Apparatus having rest states have been described by Kralik, in US Patent 6,538,541, where a 2-position switch is described, using a coil to move an armature between the two positions. Bae, et al. in US Patent 6,532,136, describes a hard-disk drive magnetic latch, with a coil which is energized for normal operation, and de-energized for parking. US Patent 4,706,055, by Uetsuhara, describes an electromagnetic actuator having a member with a multiplicity of poles, in proximity with a magnet whose flux is modulated by a coil. The application of to a general mechanism with rest-states is not described here.

Some more relevant prior art is described below. In http://www.eskimo.com/~billb, use of inductive force in various scientific demonstrations is described. But the applications described here, and the ability to perform sophisticated speed/timing/force control in a single cycle in motor driven loads, and general mechanisms is not described. The single mention of timing control is dropping a neodymium magnet down an inclined plane with a conductive member embedded in the plane, and slowing down of the magnet when it goes over the conductive member. In http://my.execpc.com/~rhoadley/magindex.htm, a pendulum consisting of a solid or slotted conducting member oscillating near a magnet is described, and it is stated that by slotting the conducting member, the time to stop is greatly increased. But neither control of motors, with possibly sophisticated

speed/timing/force control (with possibly multiple speeds in a cycle, etc.), nor the use in applications described here, is described.

None of this prior art, describes speed control techniques applicable to SAs, which are unpowered (i.e. human powered) or appliances powered by one or two (or a few) 1.5V batteries. Also not described are timing control techniques, wherein speed can be changed in a single cycle of rotation for motors, or a single cycle of operation for general mechanisms. The invention can considerably decouple the problem of generating a correct mechanism path (kinematics), from the associated problem of generating a correct velocity/timing/force for the mechanism (dynamics). Current state-of-art requires close attention to be paid to the interaction of kinematics and dynamics in mechanism design. In addition, none of this art describes the use of rest-states, appearing when multiple parts of the apparatus are magnets or ferromagnetic material. From one point of view, our work can be regarded as generalizations of both electric machines and general mechanisms, to yield a new class of devices hereafter called electrical mechanisms.

Additionally, this prior art does not indicate how to generate speed/timing/force control, with possible rest-states, that can be varied by the user, as desired (e.g. high speeds can be generated under user control, where a "desirable motion" occurs, and low speed where potentially risky mechanism motions occur, etc.).

Finally, none of the prior art, described the usage and benefits of motion control in SAs. We teach the use of motion control techniques in such apparatus, and potential benefits.

BRIEF SUMMARY OF INVENTION:

The invention has two parts:

(1) Techniques to achieve motion control (possibly with rest-states), using electromagnetic force, possibly using induction and/or hysteresis, in various apparatus. By control of motion we mean control of ***speed of operation of the apparatus(speed), time taken by the apparatus to reach one or more significant positions (possibly but not exclusively rest-states - timing), and force/torques***

<u>exerted on one or more sources of power to the apparatus, one or more external loads, or internally between various pieces of the apparatus</u>. ***<u>The control of motion enables, of course, control of position of the apparatus.</u>*** Our techniques are all based on the interaction amongst one or more magnets (primarily permanent but can be electromagnets also), and conductive or ferromagnetic strips, sheets, rods, etc (hereafter referred to as *induction/hysteresis members*), generating the electromagnetic force. These magnets and induction/hysteresis members can be solid, slotted, or perforated, can have various geometries, various dimensions (length, width, height/thickness), and be of various conductive, ferromagnetic, partially conductive, partially ferromagnetic, or composite materials. The three forms of our technique, which can be used in conjunction, are:

(a) Power Control: This method, applicable to electric motors, achieves motion control by physically changing the magnetic flux path geometry, achieving modulation of the magnetic field inside the machine. The state-of-art in field control, typically changes the current exciting a field coil [8]. The state-of-art of modulation of permanent-magnet field in [4], has not been applied to a low cost electric motor, for controlling speed.

(b) Power Transmission Control: This method achieves motion control by using electromagnetic force transmission controllable by varying the magnetic flux path and/or induction/hysteresis member geometry, and is a generalization of electromagnetic clutches.

(c) Load Control: Control of electromagnetic load here, is also primarily based on the geometry, and relative positioning of magnets and/or induction/hysteresis members. Both the geometry and the relative positioning of the magnet or magnets and the induction/hysteresis members can optionally be changed.

These amount of control exerted on the apparatus by the three techniques can be constant with time, periodically varying, or aperiodically varying, as desired by the user. The invention can be used in conjunction with all existing methods of motion control also. The invention is excellently suited for applications wherein low cost is primary, as it is *primarily but not exclusively a passive method*, and does not require expensive powered microprocessor+servo/ similar devices.

[redacted]

(2) Application of aforesaid motion control technique to apparatus that have hitherto not used them, and the realization of new functionality in the aforesaid apparatus, as well as realization of new apparatus utilizing our techniques.

<u>We reiterate that while the invention is primarily targeted at low cost mass-market applications (SAs), this does not limit its use in other contexts, e.g. in high reliability environments due to simplicity of design, very high-performance apparatus due to easy modification of apparatus static and dynamic behaviour to simplify control, etc.(we present examples of such use also)</u>

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF DRAWING

Figure 1: Key Challenge in the Invention: Slowly varying source of low-voltage power (1-3 V), or unpowered device.

Figure 2 (a) Magnet Monopole (b) Magnet Dipole inducing closed loop eddy-current (top view)

Figure 3 (a) Magnet M near Induction Member (b) Magnet M farther away, reducing field

Figure 4 (a) Magnets close to each other (b) Magnets farther away, reducing field

Figure 5: (a) Air-Gap Ag1 modulation by moving magnets M and back-iron further away (b) Air-gap modulation by changing reluctance of auxiliary Air-Gap Ag2, by moving pole piece P.

Figure 6: Combined Induction/Hysteresis Member (Copper Disk with four steel inserts).

Figure 7: Induction Disk, Magnet, and Contacting Bearing (a) 3-D View (b) Axial Cross Section

Figure 8: Field weakening by changing the relative distance between pole pieces (a) Strong Field (b) Weak Field: Both (a) and (b) are views looking axially directly at the rotor.

Figure 9: Changing interaction between field and rotor (a) Full interaction (b) Partial interaction

Figure 10 Modified Motor with torque which changes within a single cycle, useful for timing control. (a) High Torque Configuration, due to low air gap and high magnetic field (b) Low Torque configuration, due to high airgap and low magnetic field (c) Cylindrical non-ferromagnetic rotor, showing low torque due to ferromagnetic insert at right angles to flux path. (d) Cylindrical non-ferromagnetic (with ferromagnetic insert) rotor, with asymmetric magnetic field, and variable speed/torque due to dissimilar pole pieces

Figure 11 Gear Train with customizable speed-torque characteristics

Figure 12 Gear Train with customizable speed-torque characteristics, with contacting bearing

Figure 13: Basic Motion Control using controllable induction (a) High Speed (b) Medium Speed (c) Low Speed. (d) Magnet M partially outside disk, reducing induction and causing speed increase. Speed is controlled by varying the position of a field generating

device (magnet M in red), with respect to axis or rotation A (blue) *Alternative structures can be used for magnet M (Section A*

Figure 14: (a) Low Speed, with Magnet M (or magnets M) close to disk (b) Higher speed with Magnet M (or magnets M) far from disk. (c) Highest speed with Magnet M (Magnets M) farthest from disk.

Figure 15: Induction Disk showing multiple magnets, with flux return paths

Figure 16 (a) Magnets facing each other with controllable airgap (b) One magnet in reluctance circuit, but not in air-gap of induction disk. Induction disk not shown (see Figure 15).

Figure 17: Induction Drum with Magnets M

Figure 18: (a) Alternative Structure corresponding to Figure 7 showing bearing supporting disk, with magnets part of bearing structure. (b) Cross Section View of (a)

Figure 19: (a) Magnet M (or magnets M) over conducting/ferromagnetic disk sector, maximum torque (b) Magnet M (or magnets M) at periphery of conducting/ferromagnetic sector, lower torque (c) Magnet M (or magnets M) over cutout sector, close-to-zero inductive/hysteresis torque.

Figure 20: Timing Control Induction Disk with three cutouts.

Figure 21: Timing Control Induction Disk, with symmetric cutouts, and multiple magnets, to yield zero net force

Figure 22: Timing Control Induction Disk with Slotted/Perforated Area.

Figure 23: Programmable Timing Control Disk showing placement of slots and induction members (conductive disk sectors), which can be selectively inserted into slots to programmably control timing. The proper fastening of conductive disk sectors to the frame, in a removable fashion, can be done by a variety of means well known in the art.

Figure 24: Power Control for a Reciprocating Mechanism (a) Maximum Force/Torque position (b) Minimum Force/Torque Position

Figure 25: Power Transmission Control For a Reciprocating Mechanism.(a) The drive pin DP2 is omitted (or modified), and auxiliary constraints keeping connecting rod CR in the vicinity of reciprocating shaft RS are present. Magnet M (or Magnets M) are attached to CR. Inductive force is produced in RS, due to slip between CR and RS. (b) Modification of drive pin DP2. A slot is cutout in RS, in which DP2 can slide. The slot serves to

constrain CR to be in proximity with RS. No vertical force is transmitted through the slot. Vertical force is due to induction in RS due to field from magnet M (or magnets M)

Figure 26: Reciprocating mechanism with Load control

Figure 27: Mechanism Timing Change by induction force

Figure 28: 4-bar linkage with magnetic interaction between links, with capability to form mechanical logic.

Figure 29: Magnetization of Connecting Pins and Housing (a) Pin and Housing together (b) Magnetization of exemplarily hollow pin (c) Magnetization of Housing

Figure 30: Two stable (a), (b) and two unstable (c), (d) positions of magnetic pin and pin housing, offset by one quarter revolution each.

Figure 31: Screw mechanism with controllable possibly non-uniform torque.

Figure 32: CD mechanism incorporating induction braking to prevent violent ejection

Figure 33: Top View of Carrom Board, showing magnets beneath board, and induction members in the strikers and/or pieces.

Figure 34: Extensible Tether with Induction Braking (front View)

Figure 35: Airplane with Maglev, Magnets on Ground, and Induction Member on aircraft.

Figure 36: Electromagnetic Manipulator lifting exemplarily screws, and tightening them

Figure 37 Bubble Vibration Toy

Figure 38: Variants of Bubble Vibration toy, showing different kinds of frames, and different modes of excitation (translation + rotation), possibly using auxiliary frames.

Figure 39 Soap Film Frame Assembly having multiple sections, of different shapes and dimensions, and different resonant frequencies. Changing the vibration frequency, will selectively excite different sections, changing the vibration pattern visible to the viewer.

Figure 40: Paper Dispenser with Inductive Speed Control (Exemplary Embodiment)

Figure 41 Well Pulley Inductive Speed Control (Exemplary Embodiment)

Figure 42 Rotating Display Turntable, whose speed can be controlled using induction device.

Figure 43 Rotating Display Turntable, whose speed can be controlled using induction device, with cutout

Figure 44 Rotating Display Turntable, whose speed can be controlled using induction device, with cutout, which can be optionally programmable

Figure 45 Rotating Doll

Figure 46 Rotating Lollipop

Figure 47: (a) Timing Control Induction Disk, used as a timing CAM

Figure 48 Powered Toothbrush with speed control using induction.

Figure 49 Drawer (Top View) with induction brake to prevent excessively violent opening/closing.

Figure 50: Apparatus using a hinge, enhanced to reduce excessively high-speed operation.

Figure 51: Induction Speed Limiting for bin lid. Induction Member positioned near edge of lid for maximum speed.

Figure 52: Magnetically Adjustable Pedestal, showing two pot platforms, whose height/angular position can be adjusted

Figure 53 (a) Ferromagnetic Grooved pedestal, and (b) Matching projections on magnet/magnets attaching the platform(s) to the pedestal. The matched grooves and projections enhance holding force, and prevent motion in any direction. The ferromagnetic pedestal can be spherical, or any other shape, with grooves on its surface. Magnet/magnets holding the platforms to the pedestal

Figure 54: Magnetic Cabling Clip holding cables to ferromagnetic object (e.g. computer cover).

DETAILED DESCRIPTION:

We shall first describe the techniques of the invention in order, Power Control (PC), Power Transmission Control (PTC), and Load Control (LC), for rotating apparatus powered by electric motors. Then, we shall generalize our techniques to general mechanisms. We describe our techniques with reference to both apparatus without rest states, and those with rest states. Finally, we describe apparatus in which our techniques have been applied, and the resultant novel functionality. Much of the discussion will center on Load Control (it can be applied to unpowered devices also), but the ideas are equally applicable to Power Control and Power Transmission Control.

We shall primarily discuss electromagnetic induction based techniques, but the techniques can be directly translated into hysteresis based techniques, as well as techniques based on magnetic attraction/repulsion, and are additionally stated by implication of this statement here. Where required, we shall mention differences (see Section A[4], and A[5]). We describe our techniques primarily in terms of fixed magnets (permanent or electromagnets) inducing currents in moving induction members, but our methods are equally applicable when the magnets move and the induction members are stationary, or both move relative to each other. Applicability of our techniques to these cases is stated by implication of this statement here.

To begin, we briefly indicate the challenges in motion control in the targeted apparatus, followed by some generic issues in controlling magnetic flux.

MOTION CONTROL FOR BATTERY OPERATED AND UNPOWERED DEVICES

The invention is primarily but not exclusively targeted at very low cost applications like bubble vibration toys, paper dispensers, display turntables, rotating dolls, rotating Lollipops, toothbrushes, racing cars, drawers, etc. Speed control in these devices should typically be smooth, but not necessarily set to an accurate value.

In these applications (Figure 1), the apparatus is either unpowered (paper dispensers, drawers), or uses an electric motor running off one or two (or a few) 1.5 V AA or AAA batteries. The available power hence ranges from 1 to 3 V, precluding any cost-effective

electronic control of motion. Speed control using resistors reduces the available motor power, and requires one or more power resistors, and is especially prone to stick-slip at low speeds. In principle, current control using transistors driven by varying base drive can be attempted, but is susceptible to varying transistor current gain, and is again prone to slip-stick at low speeds. In contrast, our passive method does not require any electronics, has no slip-stick, can be implemented with low dissipation by a proper choice of motor impedance, works equally well in unpowered applications, and can be implemented at very low cost. The method is quite general, and can be equally applied to apparatus utilizing other control techniques like pulse-width-modulation, to systems using higher voltage than previously described, and to systems where lowering of cost is not necessarily a major objective. The method works using a combination of Power Control, Power Transmission Control, and Load Control.

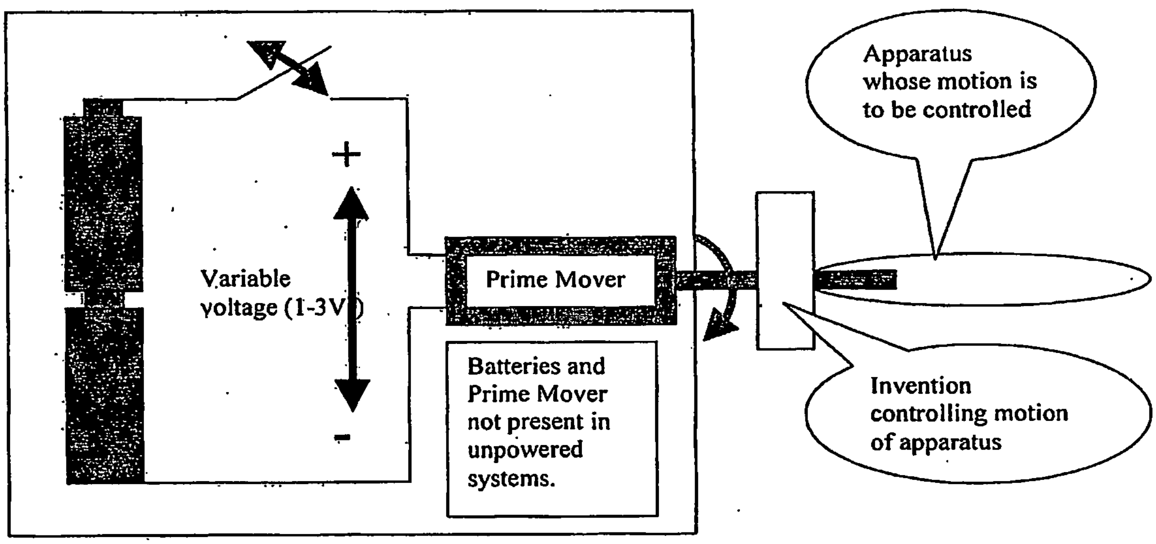


Figure 1: Key Challenge in the Invention: Slowly varying source of low-voltage power (1-3 V), or unpowered device.

In a preferred embodiment of the invention, the electrical excitation to the prime mover (motor, if present) remains fixed at the nominally constant battery voltage, except for switching it on/off, throughout the operation of the apparatus. Motion control consists of application of controllable electromagnetic force, without electronics. In most prior art, electromagnetic force is used to brake an apparatus intermittently, under electronics control. Additionally, the use of motion control itself, and particularly induction/hysteresis motion control in unpowered apparatus is new.

A. Generic Methods of Controlling Magnetic Flux, Induced Currents, Hysteresis, and Force/Torque

This invention generates controlled forces/torques, by controlling one or more of (a) the magnetic flux in a desired region (b) the induced currents/field hysteresis due to the flux interacting with induction/hysteresis members (conductors/ferromagnetic material) in any desired region. Changing either the flux and/or induced current/hysteresis changes the force/torque. In all that follows, mechanical means (e.g. screws, sliders, etc.) of performing any desired motions of either the flux generating or the induction/hysteresis members, are assumed to be available, and will not be described. We first consider induction methods, and then outline differences between the use of induction members and hysteresis members, and multiple flux sources.

[1] Control of Magnetic Flux

As is well known [4],[8],[9], a first approximation for the magnetic flux in a region is given by the magneto-motive-force (*mmf*), divided by the reluctance of the paths traversed by the magnetic flux. Changing either the *mmf* or the reluctance will change the magnetic flux. In apparatus we consider, the magnetic flux is predominantly but not exclusively produced by permanent magnets (typically high-strength neodymium magnets). In this case, the *mmf*, in a given apparatus is fixed by the geometry, size, and strength of the permanent magnets used[1]..The reluctance of the flux path, however, can be changed, by changing any air-gaps present [4]; [8], [9]. Additionally, in regions of non-uniform magnetic fields, changing the position of the region will change the flux and/or the induced currents and forces due to it. All of *these methods are well known, and are embodied as follows in this invention, and our claims apply to the use of each one of these methods*. The embodiments are classified according to

- Number of magnets
- Presence of flux return path (back-iron).
- Presence of conductive material (induction members) in which eddy-currents leading to inductive forces are generated.

[1] If electromagnets are used, the mmf and hence the flux can be changed by changing the current in the coils. This method can be used in conjunction with all the techniques mentioned here.

Unless otherwise mentioned, for simplicity of illustration, we chose a cylindrical disk magnet structure, axially magnetized (one circular face is north, another south), in all that follows. In many embodiments, the magnets poles and flux paths are designed as dipoles, to force the induced currents to follow closed loops (Figure 2). Our claims are equally valid for such and arbitrary magnet structures.

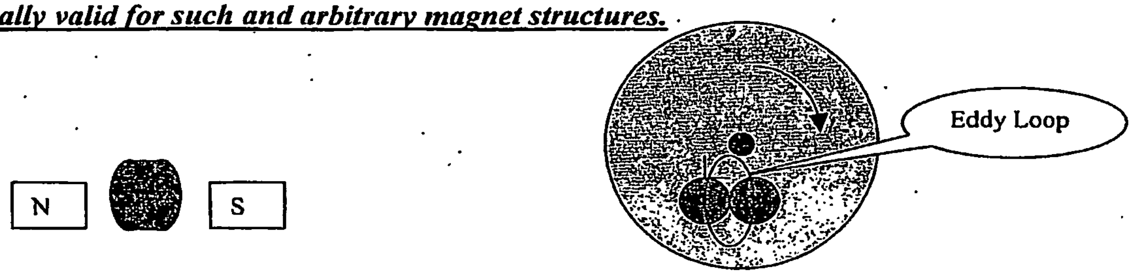


Figure 2 (a) Magnet Monopole (b) Magnet Dipole inducing closed loop eddy-current (top view)

1. Single magnet, no flux-return path: The field/flux is controlled by varying the position of the magnet relative to the desired region. The desired region can be an induction member (Figure 3), a rotor, etc.

Figure 3 (a) Magnet M near Induction Member (b) Magnet M farther away, reducing field

2. Multiple Magnets, no flux return path: Here, in addition to changing the position of the magnets relative to the desired region (containing induction members/rotors, etc.), the positioning of the magnets relative to one another, can change the field and hence the flux (Figure 4).

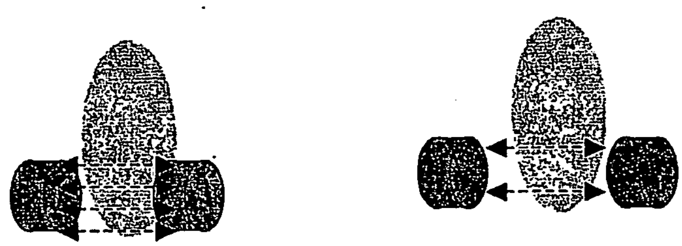


Figure 4 (a) Magnets close to each other (b) Magnets farther away, reducing field

3. One or more magnets with Flux Return Path: Here, additionally to 1 and 2 above, any means of changing the effective reluctance of any flux return path, will cause modulation

of the field. Figure 5 illustrates this for the case of two magnets, with flux return paths using ferromagnetic material (back-iron). Flux can be changed by moving two magnets further away, increasing air-gap Ag1 (Figure 5 (a)), or keeping the magnets stationary, but changing the size of an auxiliary air-gap Ag2 in the magnetic circuit by moving a ferromagnetic insert P (Figure 5 (b)), or any similar means, where the flux path reluctance is changed by mechanical motion of one or more of its constituents. This is well known in the state-of-art [4].

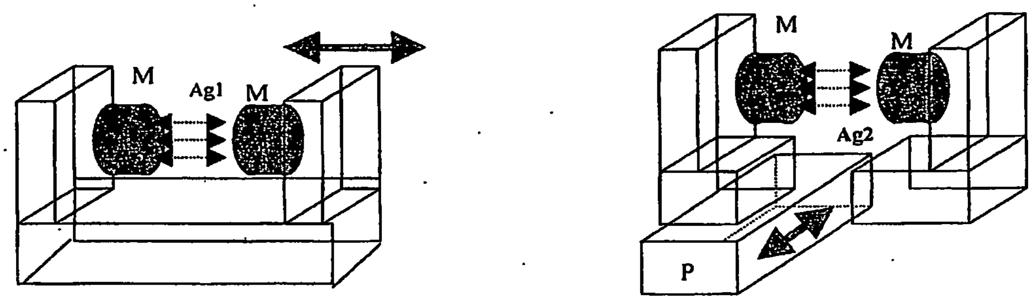


Figure 5: (a) Air-Gap Ag1 modulation by moving magnets M and back-iron further away (b) Air-gap modulation by changing reluctance of auxiliary Air-Gap Ag2, by moving pole piece P.

In all that follows, we shall for simplicity, often depict a single magnet inducing currents/force in an induction member. It should be understood that the single magnet can be replaced by any of the assemblies described above.

[2] Control of Induced Force/Current by changing Induction Member & Magnet Properties

It is also well known [6][8][9][10][12] that the induced current, and hence induced force is dependent both on the flux, and the geometry of the induction member, its dimensions (length, width, thickness), and its effective conductivity. The effective conductivity depends on the material, its texture, i.e. whether it is solid, slotted, perforated, etc. Changing any of these parameters changes the induced current, and hence the induced force/torque. The induction members may be merged with other materials, to achieve properties other than conductivity. Exemplarily, they could be part of multi-layer assemblies, satisfying desired mechanical strength properties in addition, to conductivity etc. Alternatively, they could be coated for corrosion resistance, etc. **We additionally note that the same applies to the magnets, whose geometry, dimensions, material, number, etc, can be analogous chosen to suit.**

[3] Dynamically controlling Force by changing flux and induction member properties during operation of Apparatus

This pertains to the use of our techniques to control non-uniform motion (Section D, and Section E) in apparatus incorporating general mechanisms. Flux changes can be made in a dynamic manner, as a part of the regular operation of the apparatus. Exemplarily, the flux path can be made to periodically change reluctance, by the techniques outlined above. This flux path change can be automatically driven by the operation of the apparatus itself. Flux changes can also be made by dynamically changing the shape of the magnets themselves.

Even for a given fixed flux, the strength of the induced current, and hence the induced force/torque can be modulated by

[1] Changing the induction member thickness, with maximum thickness at those positions where maximum force is desired. In positions where zero force is desired, the thickness can be zero, i.e. the conductive material is cutout at those positions.

[2] Using higher conductivity material at positions where more inductive force is desired (e.g. A copper sector in a Al disk, etc.)

[3] Using an induction member with varying degrees of material thickness, slottness, perforatedness, etc, or any means which effectively modulates conductivity.

[4] Using induction members of different geometry, e.g. induction drums, and members of other geometry well known in the state-of-art. The induction member geometry can change in different positions, e.g. a disk having a raised cylindrical flange, which occupies only part of the disk circumference.

[5] Using multiple induction members, possibly of different geometry, dimensions, and material properties, with one or more magnets.

All these modifications to the inductive strength can either made during the manufacture of the apparatus, or customizable at the time of use of the apparatus, by slots being provided for attaching modifications to induction members, magnets, etc. (Figure 23).

[4] Differences between force/torque control using Induction and using Hysteresis

Hysteresis effects [6][8][9][10][12] can be used instead of induction-effects to generate controllable force/torque. Hysteresis members of various materials, sizes, shapes, etc. can

be designed to apply a desired force/torque, analogous to the design of the induction members above. The major difference is that hysteresis forces/torques are independent (to a first approximation) of speed, while induction forces/torques are proportional to speed. Induction members provide automatic negative feedback, by increasing force/torque as speed increases, and can be used without slip-stick at very low speeds also. If hysteresis members are used, the forces/torques are constant with speed. Speed can be controlled by Power Control or Power Transmission Control. Load control using fixed hysteresis members can be done by changing the flux, thus changing the strength of the hysteresis effect, or by changing the radial position of the hysteresis effect, thus increasing torque while the force is kept constant. Other than these aspects, the control of speed using hysteresis and induction members is identical.

Hysteresis and induction members can be used in conjunction with each other, to provide force characteristics having a fixed force component independent of speed, and a variable component linearly proportional to speed. Separate induction and hysteresis members, or members having a combination of hysteresis and induction material can be used for this purpose (for example, copper inserts in a steel disc, or use of a copper-iron alloy possibly made using power metallurgy). The force production may be changed as desired with time, exemplarily alternating induction, hysteresis, etc. For example, the mixed induction/hysteresis disk in Figure 6 has four steel hysteresis inserts in a copper induction disk, and can be used for sophisticated timing control (Section D). One important feature of hysteresis members, shared with magnetic members in the next Section A[5], when the motion is non-uniform, is that hysteresis members, being ferromagnetic, are attracted to the magnets. This introduces preferred ***rest positions*** for the apparatus, which can be exploited to provide latching behaviour (monostable, bistable, etc). Induction members, which are typically copper/aluminum, do not introduce preferred rest positions.

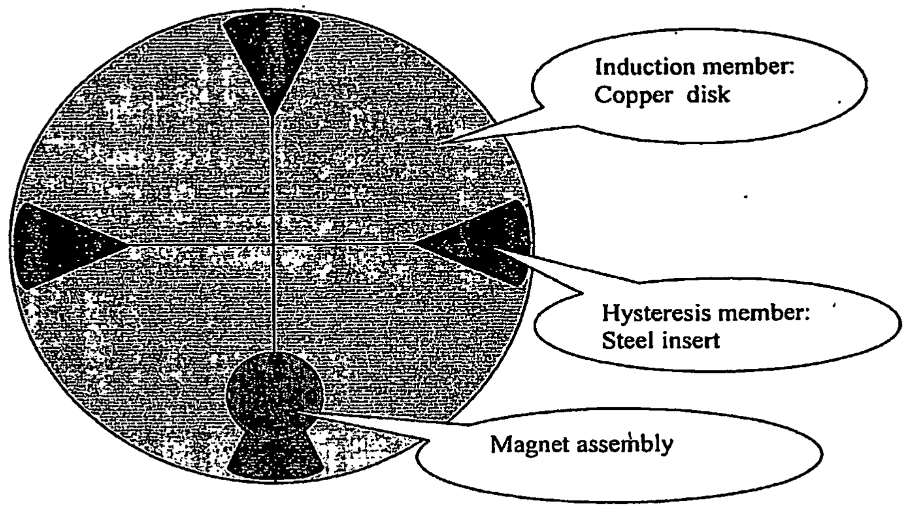


Figure 6: Combined Induction/Hysteresis Member (Copper Disk with four steel inserts).

[5] Issues when both interacting members have independently produced magnetic fields

This issue arises when magnets are used both to generate the flux, as well as interact with it to modulate motion (e.g. a magnet on the moving induction/hysteresis member itself). Such ***autonomously magnetic interacting members*** introduce one major new issue, in that now because of the presence of both magnets, there are preferred rest positions for the apparatus, keeping like poles as far apart as possible, and unlike poles as near as possible. Mechanical monostables, bistables, and astables can be thus designed, and cascaded to perform mechanical logic. Design using such devices can be carried out by techniques similar to induction/hysteresis members, together with well known electromagnetic field interaction equations, using possibly principles of virtual work [10][11][12][13][14].

Induction forces, Hysteresis forces, and forces produced using autonomously magnetic interacting members, can be used solely, or in any combination.

[6] Reduction of Random Disturbances to the Induced Force/Torque

The force/torque exerted on the apparatus, depends on the relative position of the induction/hysteresis member, and the magnet or magnets generating the flux (in addition to other factors like geometry, size, speed). Random disturbances encountered during motion, can cause the relative position of the induction/hysteresis member and magnet/magnets to change, causing the force/torque to vary randomly, and disturbing the resulting motion. Various mechanical means of minimizing the random disturbances are known, including damping, constraining the relative motion of the magnet or magnets, and induction members, using bearings, etc.

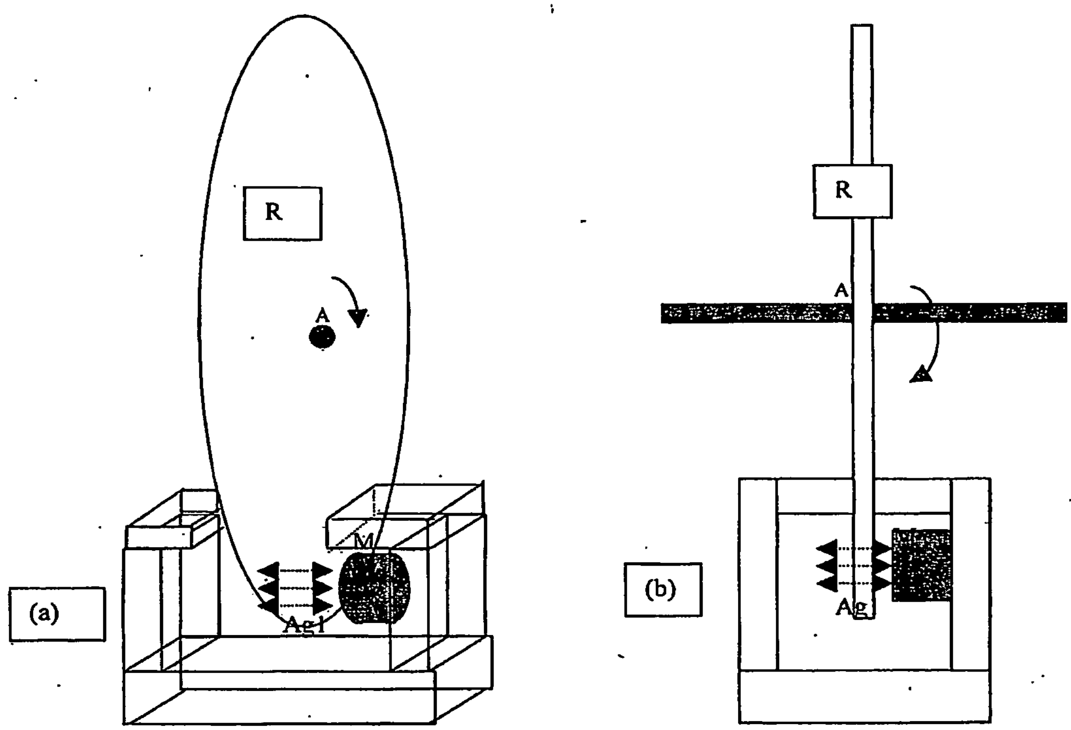


Figure 7: Induction Disk, Magnet, and Contacting Bearing (a) 3-D View (b) Axial Cross Section

A preferred low cost embodiment of these ideas in our invention, applicable when the induction member moves, and the magnet is stationary, is the structure shown in Figure 7. Figure 7 (showing the Load Control structure of Figure 13, below), shows a single magnet M near an induction member R, applying induction torque to the induction member, rotating on axle A. In addition, the structure holding the magnet is further extended towards the inside of the induction member, to form a ***low friction*** contacting bearing for the induction member (disk in this case). The bearing ensures that disk axial

vibrations are minimized, resulting in a substantially constant position of the induction member with respect to the magnet M. This helps keep the induction forces and hence speed constant (note that the bearing is low friction). Changing the speed can be achieved by either radially or axially moving the entire assembly, using apparatus not shown, as shown later in Section D on Load Control.

The technique can be used when both the induction member and the magnets move (e.g. the induction gear of Figure 11). The contacting bearing is attached to any stationary portion of the mechanism, and provides bearing support for the moving members at or near their interaction region. For the induction gear of Figure 11, this is shown in Figure 12.

Clearly this method of providing bearing support for the induction/hysteresis member or members and/or magnet or magnets, at or near their interaction region can be extended in many ways, with different kinds of bearing structures, possibly involving balls and/or rollers also.

B. POWER CONTROL (Powered devices): Physically changing Motor Geometry/Dimensions

It is well known in the state of art that the speed of a motor is changeable by changing the intensity of the field interacting with the rotor (field weakening speeds up the motor at low torque, and slows it down at high torque [8][9]). Classical techniques exploiting this behaviour typically deal with wound field coils, whose current can be controlled to generate the desired field. Unfortunately, these methods are not applicable for very low cost apparatus, operating off one or two batteries, as they assume some kind of powered control circuitry, together with power MOSFETS.

This invention achieves the control of motor delivered power, by varying the physical geometry of the motor flux path, resulting in one or more of the following

1) Change in the field strength, by increasing the reluctance of the flux path. The stator pole pieces are moved further apart in Figure 8 (b) compared to in Figure 8 (a), weakening the field. Field weakening can also be accomplished by any of the variant methods outlined in Section A (e.g. the auxiliary air-gap in Figure 5).
2) Change in the position of the field relative to the rotor. In Figure 9 (b), the rotor is partially outside the flux area, compared to Figure 9 (a), lessening the interaction between the flux field and the rotor.
3) In general a change in the "*effective*" *strength of the interaction of the field and* the rotor.

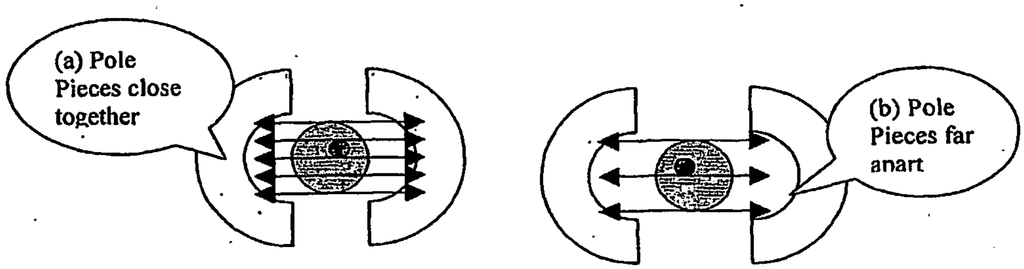


Figure 8: Field weakening by changing the relative distance between pole pieces (a) Strong Field (b) Weak Field: Both (a) and (b) are views looking axially directly at the rotor. The physical motion of the pole pieces can be accomplished by alternative means as outlined in Section A

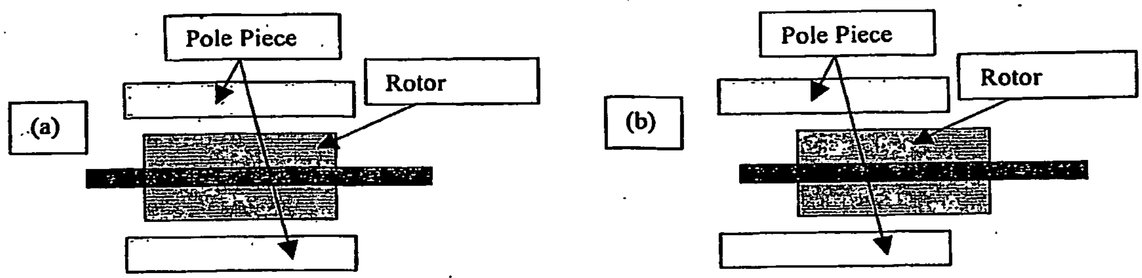


Figure 9: Changing interaction between field and rotor (a) Full interaction (b) Partial interaction. The figure shows axial cross section of the rotor and stator

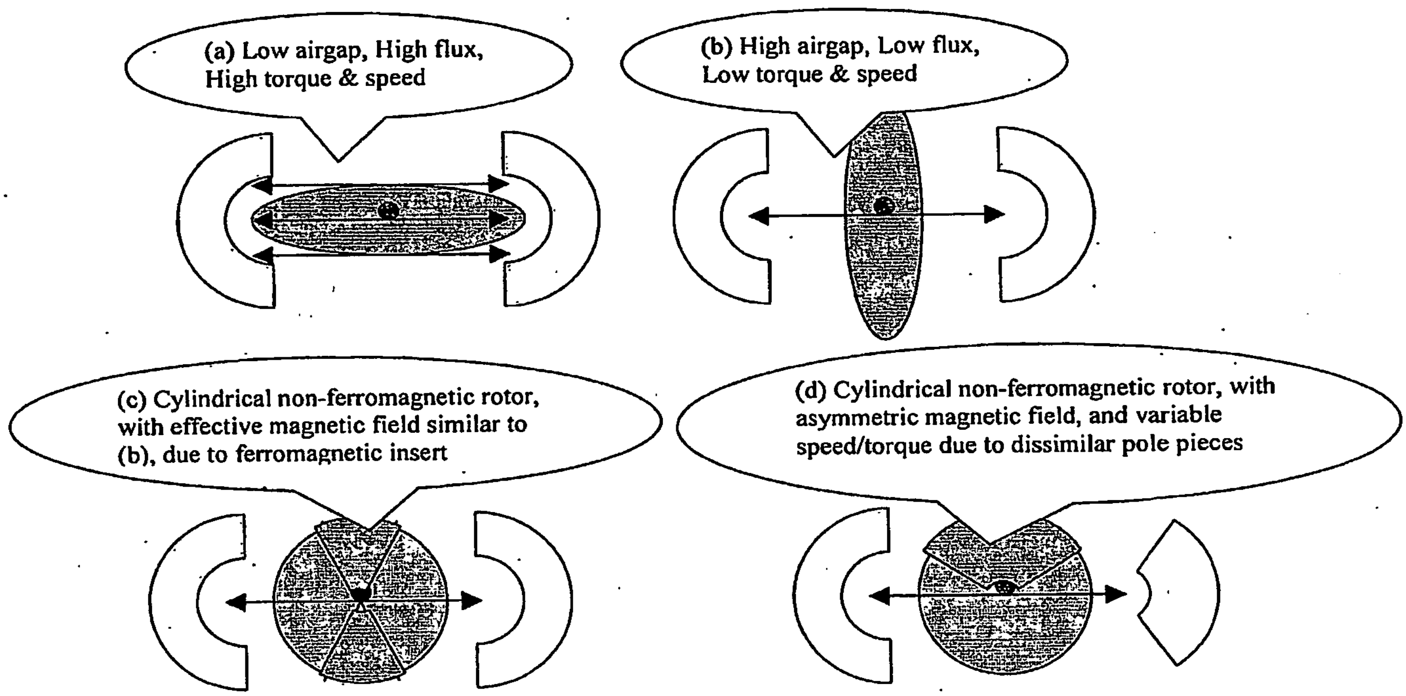


Figure 10 Modified Motor with torque which changes within a single cycle, useful for timing control. (a) High Torque Configuration, due to low air gap and high magnetic field (b) Low Torque configuration, due to high airgap and low magnetic field (c) Cylindrical non-ferromagnetic rotor, showing low torque due to ferromagnetic insert at right angles to flux path. (d) Cylindrical non-ferromagnetic (with ferromagnetic insert) rotor, with asymmetric magnetic field, and variable speed/torque due to dissimilar pole pieces

The motor delivered power can be changed within a single cycle, by making the flux and rotor geometry deliberately asymmetric. For example, the stator-rotor air-gap can be modulated within a single cycle, by using a rotor which is an elliptical cylinder. In principle any desired variation of torque with rotor angular position can be generated. Figure 10 shows such a modified motor, with windings omitted for clarity, but assumed to be on the rotor. The torque changes within a single cycle, which is useful for timing control. In (a) a High Torque Configuration is shown, with the rotor aligned parallel to

the field, resulting in a low effective air gap and high magnetic field. In (b) the torque is low, due to the rotor being aligned perpendicular to the field, resulting in a high air gap and low field. In (c), the rotor is made cylindrical of non-ferromagnetic material, but has ferromagnetic inserts at right angles to flux path, to offer a flux path similar to (b). In (d) the cylindrical non-ferromagnetic rotor with inserts is again used, but with dissimilar pole pieces. This creates an asymmetric magnetic field, and allows even more control of speed/torque. Torque/speed is high only when the ferromagnetic insert is close to the larger pole piece. Torque/speed is intermediate when the ferromagnetic insert is close to the smaller pole piece, and smallest when the inserts are perpendicular to the flux path. The positioning of these inserts can be made at the time of usage of the invention, enabling customizability of the torque with respect to angular-position (similar to that depicted in Load Control - **Figure 23**). Additionally, mechanical counterweights, etc, can be provided to minimize the vibrations due to the asymmetric structures involved. The method clearly generalizes to electromagnetic actuators used in general mechanisms, with non-cylindrical geometries.

All this enables sophisticated variation of torque with respect to angular position and time, at far lower cost compared to microprocessors, sensors and servos. The design of the magnetic circuit can be made based on well known electromagnetic and electrodynamic computational methods, which can estimate flux/force/torque, for a complex geometry, at certain angular position, using finite-element and/or boundary-element methods.

This issue is explored in greater detail in timing control using Load Control (Section D, which uses the methods of Section A, especially see Figure 19, Figure 20, Figure 21, Figure 22 and Figure 23.

C. POWER TRANSMISSION CONTROL (Powered Devices Primarily)

Electromagnetic force transmission is utilized in eddy-current and hysteresis clutches, well known in the state-of-art [5][6][10]. It is also well known [6][8][9][10][12] (Section A) that the transmission of force using induction/hysteresis, is dependent on the geometry, dimensions, "texture" (solidity/slottedness/perforatedness), and material properties of the flux generating and induction/hysteresis members. Exploitation of this property enables us to control the transmission of force/torque between a driving and a driven apparatus, in any desirable fashion. This is illustrated by the example of a gear train, using induction force, whose "effective gear ratio" can be changed, but whose resultant speed-torque characteristics are not necessarily in inverse proportion.

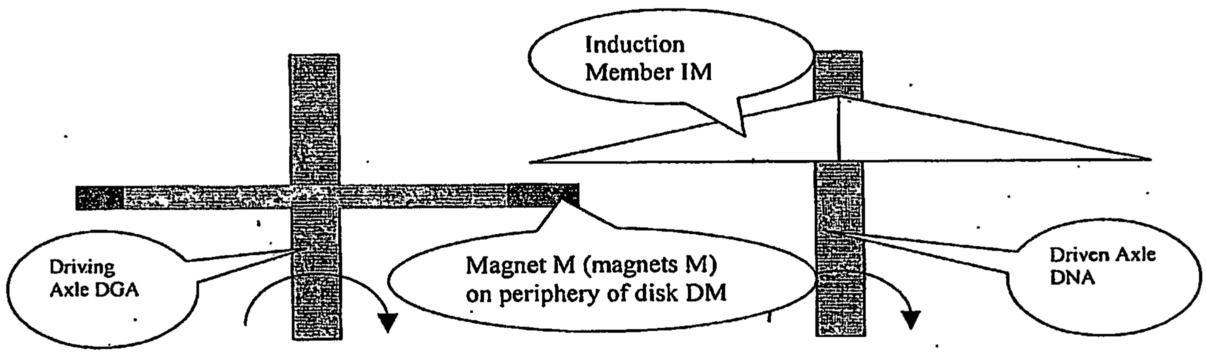


Figure 11 Gear Train with customizable speed-torque characteristics (axial cross-section view)

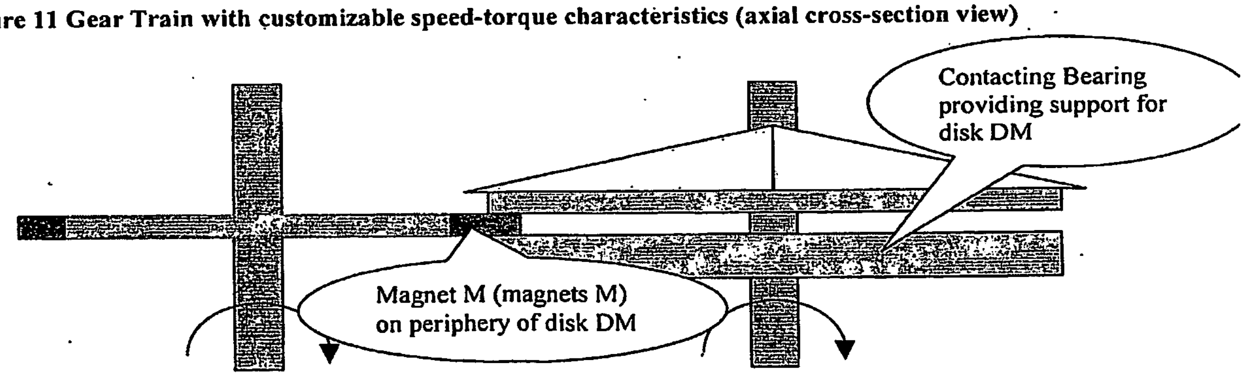


Figure 12 Gear Train with customizable speed-torque characteristics, with contacting bearing

In Figure 11 (an axial cross-section view), a driving axle DGA has one or more magnets M (as per Section A) inducing force on an induction disk IM, on a driven axle DNA.

[redacted]

Details of the magnets, and their design are described below in the section on Load Control. Unlike mechanical gears, force is induced only if there is a "slip" between the driven axle and driving axle. The thickness (or other property modulating inductive force), of driven axle DNA is more at the center. Hence as the magnets approach the center of the driven axle, the transmitted force increases, and can be arranged to cancel out the reduction in lever arm partially, fully, or even more. Hence modulating the thickness enables any desired speed-torque profile to be achieved, as "gear-ratio" is changed.

In Figure 12, a contacting bearing, attached to driven axle DNA, minimizes the effect on the force/torque, of random vibrations of the disk DM, as per the discussion in Section A.

This yields a new apparatus, a continuously adjustable electromagnetic gear train whose speed-torque transmission characteristic can be designed to suit, by modulating induction member properties (the "effective conductivity", as per Section A), and derived new apparatus comprised of multiple electromagnetic gears forming a chain, whose speed torque characteristics can be similarly designed to suit.

The torque-transmitted can be made to vary in a single rotation cycle of either the driving DGA, or driven axles DNA, by making the induction member properties change as a function of angular position. This issue is discussed in Power Control (Figure 10) and in Load Control (Section D, which uses the methods of Section A).

This Power Transmission Control technique generalizes to general mechanisms, in which case, the transmission of motive force or torque, can be made an arbitrary function of transmitted speed ratio, by suitable design of the intermediate force/torque transmission mechanism. The required electromagnetic force is generated by suitable design of the induction/hysteresis members and magnets/other flux generating members. We additionally note that such mechanisms have the property that the connection between the different members is not rigid, and can accommodate unexpected disturbances, constraints outside its kinematic design, etc., in a fail-safe fashion.

D. LOAD CONTROL (Powered and Unpowered Devices):

Load Control consists of applying a controllable electromagnetic force/torque, possibly produced by induction/hysteresis, to the apparatus, leading to change in apparatus speed/timing/force. The apparatus may be unpowered (i.e. powered by means other than a motor//IC engine, e.g. human power), or may have a prime mover.

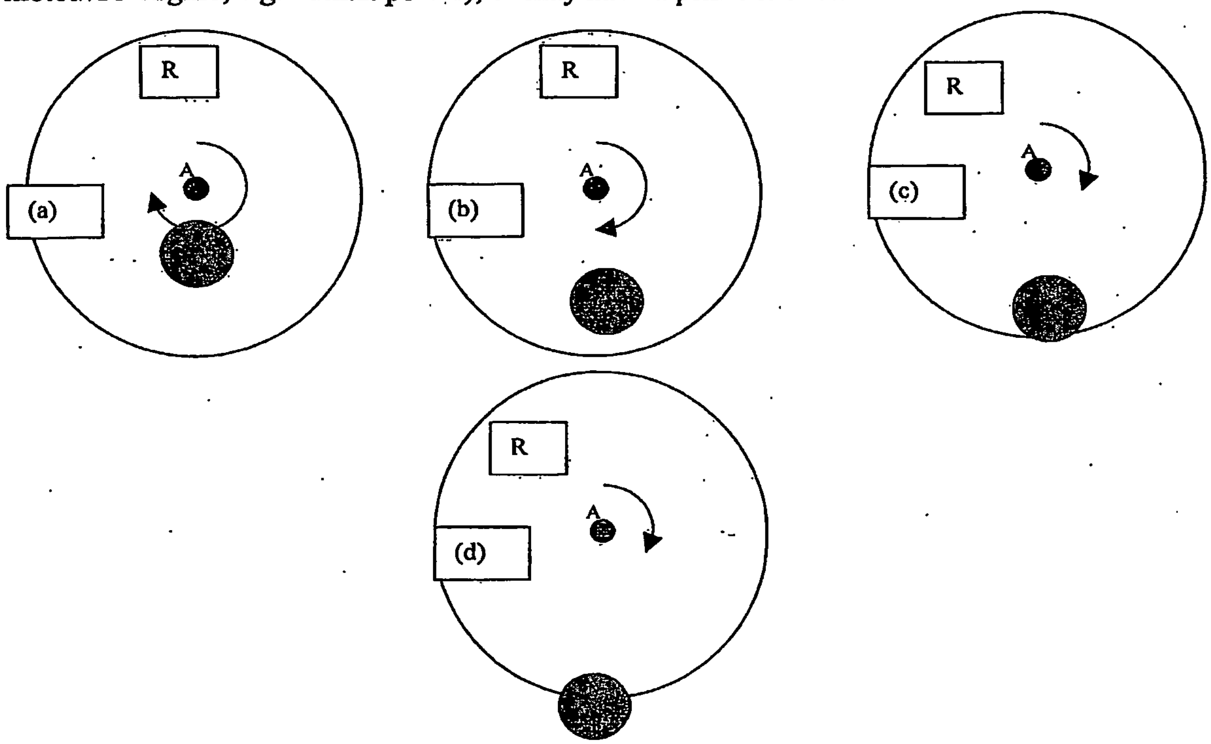


Figure 13: Basic Motion Control using controllable induction (a) High Speed (b) Medium Speed (c) Low Speed. (d) Magnet M partially outside disk, reducing induction and causing speed increase. Speed is controlled by varying the position of a field generating device (magnet M in red), with respect to axis or rotation A (blue) Alternative structures can be used for magnet M (Section A)

In Figure 13, we show an induction member shaped as a rotating conducting disk R with a magnet M positioned, with some possibly some airgap (Ag1), near it. This induction member is attached to the apparatus to be driven, which is external to Figure 13, and not shown. The apparatus is either unpowered, or is rotated by a prime mover such as an electric motor, which is external to Figure 13. As described in Section A, the magnet M may be used singly, or in combination with a plurality of similar or dissimilar magnets,

on just one side of the disk, or on both sides, with flux being connected by back-iron. When more than one magnet is used, the poles can be opposed to each other (north facing north), or complementary (north facing south).

The position of magnet M (magnets M) with respect to the axis A, can be varied, using some mechanism external to Figure 13, with (a) being the closest and (d) being the farthest. By the well-known principle of magnetic induction [6][8][9][10][11][12], the induced eddy-currents (or hysteresis effects) are least in Figure 13(a), since the relative velocity of the magnet with respect to the induction member is the smallest. As such, the induced forces are smallest in (a). The torque is relatively even smaller, due to the small distance of the small force from the axis. This leads to a high rotation speed. The magnet M (or other flux generating device) is successively, moved radially outwards in (b) and (c). This causes increased velocity between the magnet M (or other flux generating device), and the induction member, increased eddy currents, and hence increased torque resisting motion. This causes the apparatus to operate slower in (b), and slowest in (c). In (d) the magnet is partially outside the induction member, causing the apparatus to speed up due to reduced overlap of the field and the induction member. Hence speed control is achieved by adding a controlled amount of inductive/hysteresis load, while the prime mover is possibly (but not necessarily), continuously producing a constant amount of torque. The motion is smooth, since at low speed the high inductive load dominates any slip-stick that may be present, while slip-stick reduces, and inertial forces increase, at higher speeds. Based on the methods of flux control discussed in Section A, alternative embodiments of the invention are available, and some are described below.

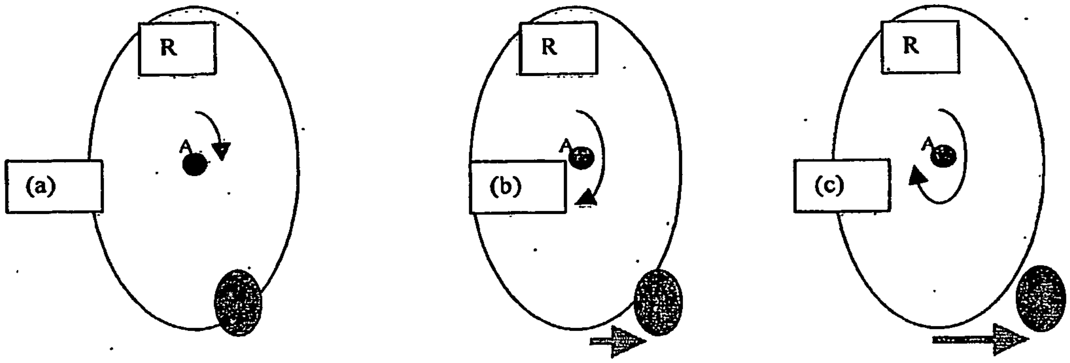


Figure 14: (a) Low Speed, with Magnet M (or magnets M) close to disk (b) Higher speed with Magnet M (or magnets M) far from disk. (c) Highest speed with Magnet M (Magnets M) farthest from disk.

Figure 14 shows speed control by moving the position of the magnet or magnets M *axially* away from the induction member, reducing the flux, while maintaining the same radial position. This has the advantage that the distribution of eddy current in the induction member R is substantially invariant from Figure 14 (a), Figure 14 (b) and Figure 14 (c), improving control linearity.

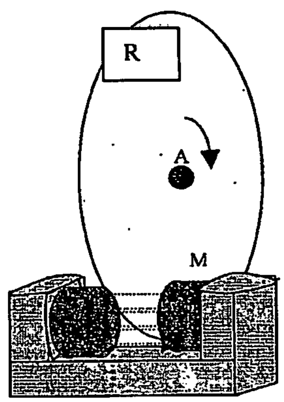


Figure 15: Induction Disk showing multiple magnets, with flux return paths

Figure 15 shows one or two magnets being used, together with ferromagnetic flux return paths, to form a partially closed magnetic circuit. The position of the assembly, relative to the axis of the induction member can be varied, and/or the flux return path reluctance can be varied by varying an auxiliary air-gap in the flux return path. This is further illustrated in Figure 16, where an airgap Ag2 is shown in the middle of the flux return path, whose dimensions can be altered by moving ferromagnetic insert P as shown. The magnet(s) M

can be on the faces of the flux return paths as in Figure 16 (a), or somewhere else in the flux return path, as in Figure 16 (b).

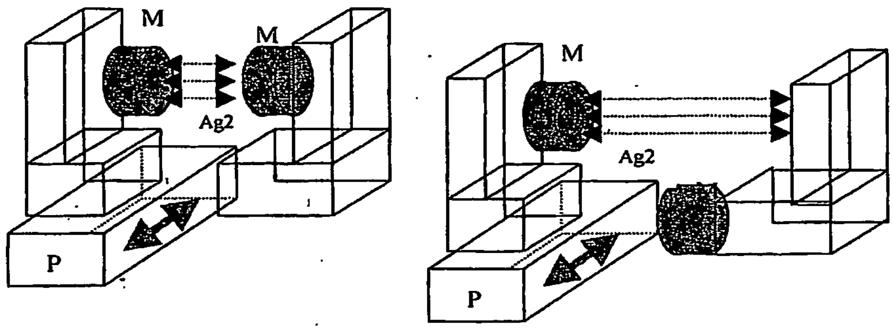


Figure 16 (a) Magnets facing each other with controllable airgap (b) One magnet in reluctance circuit, but not in air-gap of induction disk. Induction disk not shown (see Figure 15).

Many alternative geometries for the induction member are possible, e.g. an induction drum, as shown in Figure 17. Here the magnets are positioned such that the field crosses the induction drum. Inductive force and hence torque can be varied by varying the air-gap, the overlap of the magnetic field with the induction drum, or similar means, exactly analogous to the description for the induction disk above.

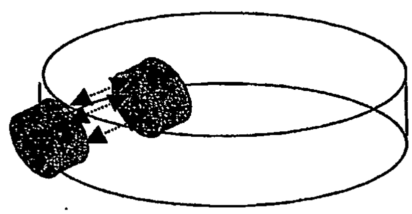


Figure 17: Induction Drum with Magnets M

In the exemplary illustrations, we have shown magnets at one position of the induction member. This creates an unbalanced force in general, which can cause the apparatus to move/shake, etc [13][14]. This unbalance can be eliminated by placing several magnets, symmetrically at equal angular positions from each other, producing a zero net force, but nonzero torque.

In all these cases, the induction force depends on the relative position of the induction disk and the magnet or magnets used. As described in Section A[6], a contacting bearing (Figure 7, on page 21) can be used to reduce the impact of random disturbances, where

the configuration of Figure 13 is shown. This method can also be used with the configuration of Figure 16, with an auxiliary airgap Ag2, and similar modifications (Figure 18). If in the configuration in Figure 18, the two magnets have complementary poles facing each other (north of one magnet facing south of another), the flux is roughly constant in the gap between the magnets. This reduces but does not eliminate the impact of axial vibrations on the induced force/torque. If the poles are opposed, however, the flux impinging on the induction disk is greatly dependent on the position, and the contacting bearing helps keep this constant with respect to vibrations.

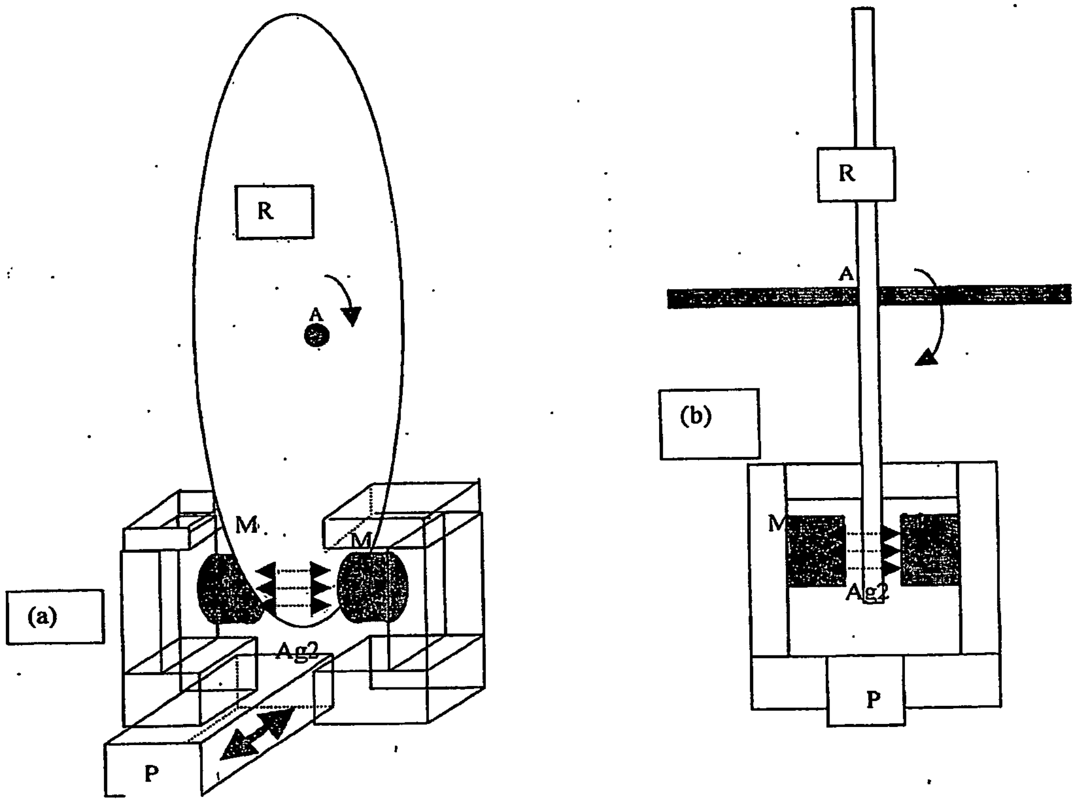


Figure 18: (a) Alternative Structure corresponding to Figure 7 showing bearing supporting disk, with magnets part of bearing structure. (b) Cross Section View of (a)

<u>It is evident that our techniques work for induction members and magnets of any geometry, which has an overlap of the magnetic field, with the induction member. We reiterate that the discussion has been in terms of fixed magnets and moving induction members, the claims apply equally to moving magnets and fixed induction members,</u>

<u>and similarly to cases where both move. We also reiterate that the claims apply equally to the use of hysteresis members, and to the use of with multiple autonomously magnetic interacting members (with the modifications outlined in Section A[4], A[5]), either singly or in conjunction with the other techniques.</u>

D.1: (LOAD CONTROL): EMBODIMENTS PERFORMING TIMING CONTROL BY CHANGING SPEED IN ONE CYCLE

The discussion so far has centered on controlling uniform motion of rotating apparatus, by controlling the relative position of one or more magnets (permanent or electromagnets), and/or one or more induction/hysteresis members. This section extends the scope of the invention to control non-uniform motion, allowing sophisticated timing to be generated, at far lower cost compared to microprocessor-controlled servos, possibly at the expense of some accuracy. **In all the discussion, the same apparatus referred to in Figure 13 through Figure 18 is considered, but with modified means of motion control.**

In Figure 19, a disk R with one sector cutout, is used as the induction member. A nonconductive material may or may not be added in the cutout portion, based on a variety of considerations (not shown). As such, the inductive force/torque produced is now ***angular position dependent***, and is maximum when the magnet M (or magnets M in any of the configurations as per Section A), is over the conducting/non cutout sectors of the induction member (Figure 19 (a)). This inductive force/torque is lower when the magnet is at the periphery of the induction member cutout sector (b), and close-to-zero when the magnet M is over the cutout/nonconductive portion (c). *This varies the speed within a single rotation, with maximum speed with the magnet over the cutout portion, and minimum speed with the magnet over the conducting portion, allowing sophisticated timing control. Note that this control can be used singly or in conjunction with moving the radial position of the magnet, changing the airgap, etc., as outlined previously (Section D).*

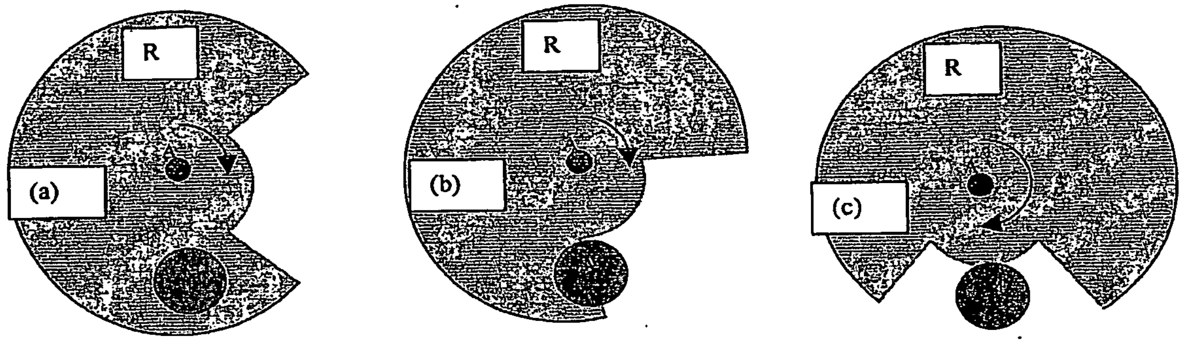


Figure 19: (a) Magnet M (or magnets M) over conducting/ferromagnetic disk sector, maximum torque (b) Magnet M (or magnets M) at periphery of conducting/ferromagnetic sector, lower torque (c) Magnet M (or magnets M) over cutout sector, close-to-zero inductive/hysteresis torque.

Multiple cutouts can be used also, resulting in multiple locations of high speed, as shown below (three cutouts are shown Figure 20).

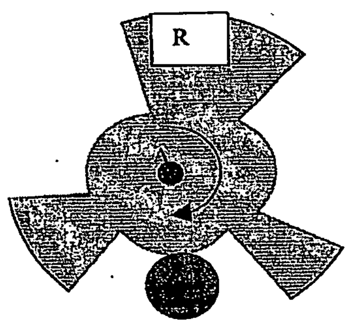


Figure 20: Timing Control Induction Disk with three cutouts.

As discussed in Section A, the structures illustrated in Figure 19 and Figure 20 have a magnet assembly only in one position, possibly generating a net shaking force to the apparatus. The net force can be eliminated by using symmetric induction members, and multiple magnet assemblies, equally angularly spaced. If K-equally angularly spaced magnet assemblies are used, the cutout structure determining the timing, is replicated K-times, over the circumference of the disk. For example, Figure 21 shows a symmetric version of Figure 20, with six cutouts instead of three, each half as big in angular extent as those of Figure 20.

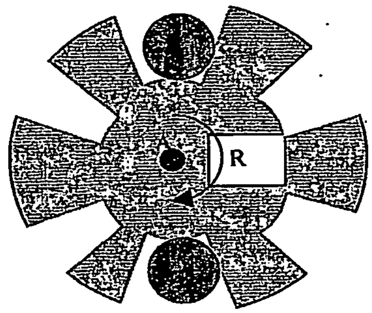


Figure 21: Timing Control Induction Disk, with symmetric cutouts, and multiple magnets, to yield zero net force, but nonzero torque

We can repeatedly slot/perforate the disk, to partially but not completely lower the induction force/torque, as shown in Figure 22. As long as the slot/hole pitch is small, the high order harmonics of the force/torque, are filtered out by the inertia of the apparatus, allowing us to vary the induction force/torque in a continuous fashion, exactly analogous to pulse-width modulation systems [8][9].

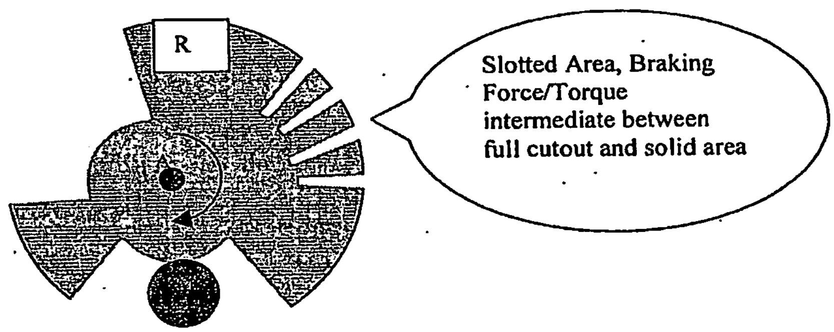


Figure 22: Timing Control Induction Disk with Slotted/Perforated Area.

In general, all the methods of controlling force/torque in Section A can be used. These include

[1] Changing the induction member (disk) thickness, with maximum thickness at those positions where more force (minimum speed) is desired

[2] Using higher conductivity material at positions where more inductive force is desired (e.g. A copper sector in a Al disk, etc.)

[3] Using an induction member with varying degrees of material thickness, slottness, perforatedness, etc, or any means which effectively modulates conductivity.

[4] Using induction members of different geometry, e.g. induction drums, and member of other geometry well known in the state-of-art. The induction member geometry can change in different positions e.g. a disk having a raised cylindrical flange, which occupies only part of the disk circumference.

[5] The same applied to the magnets, whose geometry, dimensions, material, number, etc, can be analogous chosen to suit, and can be dynamically varied during an operation cycle. For example, the disk with cutouts R in Figure 22 can be the magnet, and the magnet M become the induction disk instead.

[6] Dynamically changing the magnetic field by changing the field path in any manner, including changing the flux return path, the distance of magnet (or magnets) from induction disk, etc.

[7] Dynamically changing the shape of the magnets themselves, to selective engage induction members.

[8] Using multiple magnets and induction members, possibly of different geometry, dimensions, and material properties e.g. conductivity. For example, two disks can be used with a magnet for each (possibly at different positions).

[9] The air-gap between the magnets and the induction/hysteresis disk can be changed to change speed at all positions simultaneously (flux control, Section A).

[10] All of the above using induction effects, and additionally using hysteresis effects, and multiple autonomously magnetic interacting members, solely, or in combination. *In the case of the last two, the emergence of preferred rest positions of the apparatus enables the apparatus to offer functionality not previously present (Section A[4], and A[5]).*

The functionality of timing control is present in all these variants, and these variants are as such within the scope of this invention. While the description discusses one or a few variants, extension of the invention to include all the variants is implied by this statement here.

Additionally, the resultant timed motion can be put to several uses, for example, playing musical tones. The scope of the invention includes all such variants also.

D.2: (LOAD CONTROL): EMBODIMENTS WHERE TIMING CAN BE CHANGED DURING USE

The invention can be further enhanced to provide user customizability, by making the induction member properties changeable at time of use. These properties include but are not limited to changing the geometry of the device, its effective dimensions, effective conductivity, magnetic reluctance path, etc. **In all the discussion, the same apparatus referred to in Figure 13 through Figure 18 is considered, but with modified means of motion control.**

One embodiment of this invention is shown in Figure 23. Instead of a solid disk, we show a frame FR with *slots* for induction members IM of various types. Magnet M (or magnets M, as discussed in Section A, D) are positioned above and below the frame FR. The magnets M can be in other suitable positions so as to create a magnetic field interacting with the frame FR. The design of the slots can be of various types well known in the state-of-art, and the slots can be fully enclosing, partially enclosing, or any other kind of attachment. The slots can be nonconducting, partially conducting, or fully conducting themselves also. At the time of usage of the apparatus, the user can selectively insert induction members of various types as discussed in Section A. This introduces user programmability into the timing control, with lower speed at the places where the induction members are inserted, and higher speed where they are not. This extension of the invention admits of the following variants.

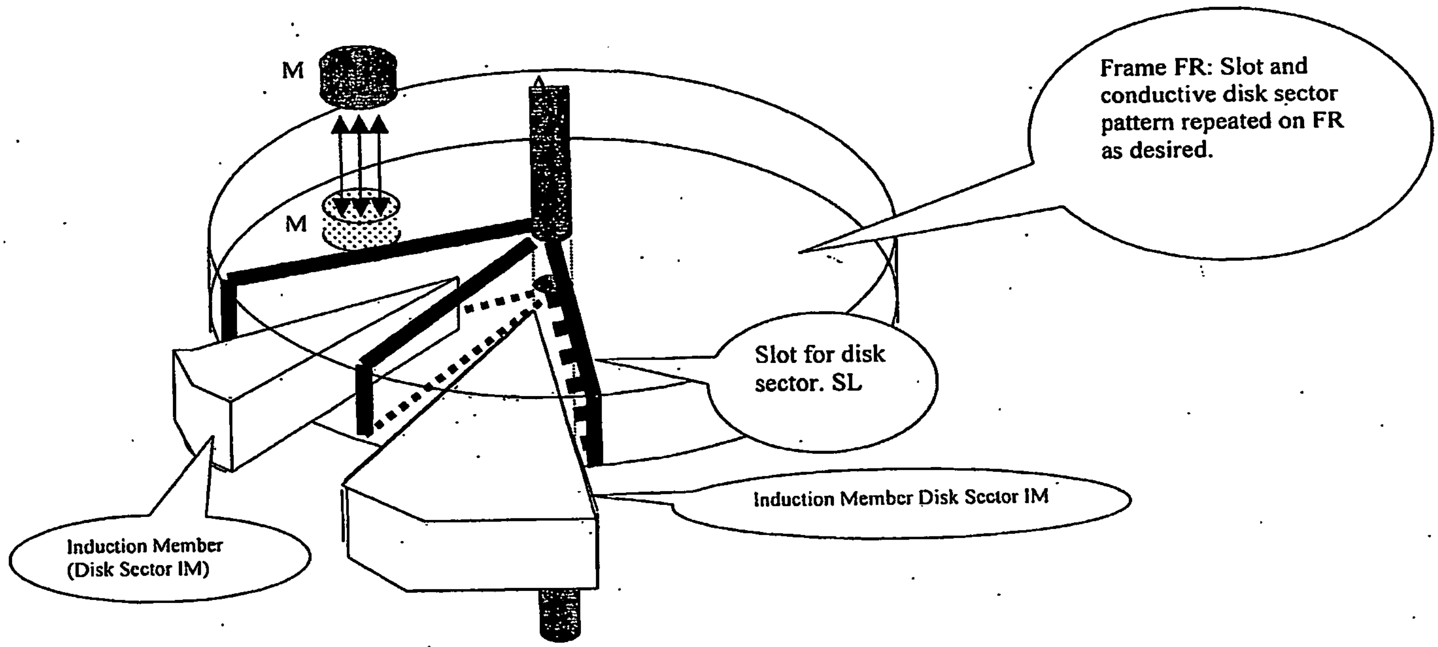


Figure 23: Programmable Timing Control Disk showing placement of slots and induction members (conductive disk sectors), which can be selectively inserted into slots to programmably control timing. The proper fastening of conductive disk sectors to the frame, in a removable fashion, can be done by a variety of means well known in the art.

1) Each type of induction member IM attached to a slot in the frame applies a certain force/torque to the rotating induction disk, when the magnet M (or magnets M) is positioned over it, resulting in a specific speed. The number of these slots, frames, and attached induction members IM can be varied, all the way from a single (small or large) frame with one slot for an insertable induction member, to multiple frames, each with multiple slots for induction members. The sizes and thickness of the slots and corresponding induction members IM can be varied. Multiple induction members can be inserted into one slot, for even more control. In general, all the variants of induction members described in Section A can be used.
2) Instead of a frame shaped like a disk, a frame shaped as an induction drum (or other geometry) can be used, following the discussion in Figure 17, with an appropriate arrangement of slots for inserting induction members.
3) Instead of an induction disk/drum, a hysteresis disk /drum can be used. In general any user changeable geometric structure (e.g. a cone whose angle can be varied) with

overlap between magnetic fields produced by one or more magnets, and one or more induction/hysteresis members, causing electromagnetic force/torque can be used (refer the discussion in *Section A, A[4], and A[5]*).

In closing, we mention two preferred embodiments of motors, where Power Control, Power Transmission Control, and Load Control are used together:

(1) ***An induction/hysteresis member, together with magnet M (magnets M) for Power Transmission Control and/or Load Control can be separately attached to the motor axle, OR***

(2) ***The induction/hysteresis member together with magnet M (magnets M) of Power Transmission Control and/or Load Control can be co-located with the rotor windings/rotor magnets of the motor, and both the powering field and the inductive/hysteresis forces varied together.***

E. EMBODIMENTS OF THE INVENTION FORMING GENERAL MECHANISMS, ABLE TO CONTROL LINEAR, ANGULAR, AND/OR POSSIBLY MULTI-DEGREE OF FREEDOM MOTION

Power Control, Power Transmission Control, and Load Control can be generalized to general mechanisms– 4-bar, Geneva, etc. [13], [14], possibly including angular displacements, multiple degrees of freedom e.g. 3-axis translation + 3-axis rotation, etc. Our definition of a general mechanism includes examples, where parts of the apparatus may be _partly or completely unconstrained_ with respect to each other.

i. _Completely Unconstrained_: An example is a carrom board set, with magnets being placed beneath the board, and the pieces and strikers having induction members inside them. This is an example of a mechanism where the pieces and strikers are completely unconstrained with respect to each other, only forces are exerted based on the position of the strikers/pieces with respect to the magnets beneath the board (in addition to mechanical striking)

ii. _Partially constrained:_ For example, the mechanisms of a set of mutually co-operating robots can be designed to apply electromagnetic forces to each other. In this case, the relative motion of the pieces of a robot relative to other pieces of the same robot is constrained, but the mechanisms of different robots are unconstrained with respect to each other in motion.

Our control techniques apply to all these variants:

1. Power Control:

   Here we consider generalizations of electric motors, with possibly changing fields produced by powered windings on portions of the mechanism, interacting with possibly changing fields in other portions, possibly produced by permanent magnets. The methods of Section A can be used to modulate both the flux, and the forces/torques possibly due to induction/hysteresis effects. The key generalization over the existing state-of-art in electric motors, and solenoid actuators, is that general non-circular/non-cylindrical geometries, possibly having multiple regions of electromagnetic interactions producing force/torque, are considered.

2. Power Transmission Control:

These are generalizations of eddy-current (and hysteresis) clutches to include members with non circular/non-cylindrical geometries, using ideas similar to Power Control.

3. Load Control:

   The induction member (hysteresis member) provides a predictable force proportional to velocity, magnet strength, and other properties as per Section A. This force can be exerted at various states (positions) in the mechanism, using possibly multiple magnets and/or multiple induction/hysteresis surfaces of suitable properties (Section A), and suitably located. This will lead to the mechanism load, and hence speed being modulated at these selected states, allowing arbitrary timing to be generated, even with the application of a constant driving force or torque (for simplicity, this is not necessary) to the whole mechanism.

The combination of power control, power transmission control, and load control enables new methods of designing mechanisms, to satisfy desired path, timing, and loading characteristics. *The design of the mechanism can be based on kinematic principles primarily[2], with the mechanism paths (for the constrained portions) being used to develop the constraint surfaces. Timing along the mechanism paths, as well as force exerted by the mechanism on the prime mover, or to the external environment in general,* can be changed as desired at low cost, using magnetic inductive force/torque applied and/or coupled at various positions, possibly in a programmable fashion. Applications of this capability are many, including but not limited to

- Motion control in low cost apparatus (SAs)
- Design of highly reliable mechanisms (e.g. in aircraft/spacecraft), due to the ability to cost-effective control speed of operation at all states of the mechanism, without using additional complexity in the mechanism, or sophisticated closed-loop control using microprocessors/sensors/servos. The latter two techniques can themselves decrease reliability, due to the additional complexity involved.

[2]Dynamic issues like force/moment balancing have also to be addressed, but can be substantially *decoupled* from the timing of the mechanism, simplifying design.

- Design of high precision mechanisms, etc. positioning devices in CNC machines, etc. Here sources of error due to mechanical backlash, zero-response zones (dead-zones), etc, can be eliminated by having a high drive to the mechanism, together with a high inductive load. The drive should be chosen to be much higher than minimum required to eliminate backlash (much more than the "stick-slip" threshold). An equally high induction load to the system, will ensure very slow, but non-zero motion (inductive load goes to zero at zero velocity), which can be exploited to provide high accuracy.

In general, let **x(t)** represent the desired time trajectory of an arbitrary point on some link/part (member) of the mechanism. For example, in a reciprocating mechanism, **x(t)** can be a point on a reciprocating shaft RS, of mass M. Newton's law applied to the member (RS) results in

$$\mathbf{x''(t) = f(x(t))/M}$$

Where **f(x(t))** is the net force exerted on the member by the prime mover through other portions of the mechanism, and the electromagnetic load (possibly due to induction or hysteresis), at position **x(t).** Let us assume that Power Control, Power Transmission Control, and Load Control are all present. If, using Power Control, **fp(x(t))** is the force generated by the prime mover, and **ft((x(t))** the percentage of force transmitted through the mechanism using Power Transmission Control, including any induction/hysteresis coupling present, and **fl(x(t))** the force due to Load Control, including any frictional losses and electromagnetic load (possibly due to induction or hysteresis), we get

$$\mathbf{f(x(t)) = fp(x(t)) * ft(x(t)) - fl(x(t)) = M\, x''(t)}$$

For a desired time trajectory **x(t),** we can find **fp(x(t)), ft(x(t))** and **fl(x(t)),** to satisfy this equation. There are clearly multiple ways this can be done.

a) Load Control Only: Here **fp(x(t))** and **ft(x(t))** are constant, or not controllable for unpowered devices. Then the amount of force required to be exerted due to Load Control is:

$$\mathbf{fl(x(t)) = fp * ft - M\, x''(t) - ff(x(t)) \sim= fp*ft - Mx''(t)}$$

Where **ff(x(t))** is the frictional force, assumed to be small due to the use of bearings, etc. This force can be used to determine induction/hysteresis member

geometry and the strengths of the magnets used, etc. One major advantage of Load Control is the lack of any stick-slip at low speeds, since both the load and force applied are much higher than the static/dynamic friction. Of course it is dissipative.

b) Power Control Only: We have

$$\mathbf{fp(x(t)) = (Mx''(t) + fl)/ft}$$

Appropriate power control can enhance mechanism energy efficiency, but in the absence of closed loop feedback, is prone to stick-slip at low speeds.

c) Power Transmission Control Only: We have

$$\mathbf{ft(x(t)) = (Mx''(t) + fl)/fp}$$

If the structures used to implement power transmission control are similar to clutches, this has the advantage that maximum force transmittable is limited, enhancing safety. Again, at low speeds this is prone to stick-slip.

d) Any two or all three taken together.

Once **fp(x(t))**, **ft(x(t))** and **fl(x(t))**, have been determined, the calculation of the magnetic parameters of the Power Control, Power Transmission Control, and Load Control apparatus can be done using standard techniques of electromagnetics and dynamics.

By suitably designing Power, Power Transmission, and Load Control, any desired time trajectory can be designed. For example, if **x(t)** is oscillatory, then an appropriate combination of controls can convert a purely sinusoidal x(t)) to one having a large number of harmonics, which is very useful in many kinds of applications e.g. vibration benches for stress testing equipment.

$$\mathbf{x(t)} = \mathrm{A}\ \mathbf{cos(\omega t)} \Rightarrow \mathbf{x(t)} = \sum[\mathrm{A_i}\ \mathbf{cos(\omega_i t)} + \mathbf{B_i}\ \mathbf{sin(\omega_i t)}]$$

An appropriate choice of controls using induction/hysteresis force changing continuously with position, can generate a broad spectrum of motion, with a close-to-continuous spectrum **X(ω)**.

$$\mathbf{x(t)} = \mathrm{A}\ \mathbf{cos(\omega t)} \Rightarrow \mathbf{x(t)} = \int \mathrm{X}(\omega) e^{(-j\omega t)}\, d\omega$$

It is clear that **x(t)** can represent an arbitrary position and angular vector, with possibly three axes of translation and three axes of rotation (in general x(t) has as many components as degrees of freedom – a robotic manipulator can easily have 10 components). In the case of rotation, we have torque instead of force, and moment of inertia instead of mass in the above equations.

Rest states of the apparatus (if hysteresis and/or multiple autonomously magnetic interacting members are used), can be determined by determining the electromagnetic energy as a function of mechanism position, and finding the minima. Dynamics between these rest states can be determined by solving the mechanism dynamic equations, accounting for any electromagnetic forces present. To synthesize an apparatus having given rest states, nonlinear optimization techniques can be used to determine the positioning of hysteresis members, and/or multiple autonomously magnetic interacting members (magnets).

This embodiment of the invention allows very low cost non-uniform speed/timing/force/torque/position control in mechanisms, compared to electronic techniques based on closed loop feedback based on microprocessors, sensors and servos. The simplicity of operation also enhances reliability (e.g. in aircraft/spacecraft mechanisms, other mass-transportation mechanisms, medical equipment mechanisms), but may sacrifice accuracy. The invention, can of course be used in conjunction with microprocessor/sensor/servo based techniques, and in these situations may help simplify the design of the closed loop control system (exemplarily by reducing dynamic range, increasing response speed, reducing random disturbances, massaging the system open loop response to be close to that desired etc.). In essence, the invention exploits the controllability and predictability of electromagnetic forces.

We shall illustrate these ideas with reference to several major examples below.

1. RECIPROCATING MECHANISM

Figure 23 shows a reciprocating mechanism, where a reciprocating shaft RS is shown attached by a pin DP2, to a connecting rod CR, driven by a prime mover which is exemplarily an electric motor, driving drive pin DP1 on drive disk DR (this may be replaced by alternative means of drive).

An embodiment of Power Control modulates the prime mover input to the mechanism. As discussed in Section B (Figure 10) use of an elliptical rotor provides torque which varies periodically in each rotation. As such, appropriate orientation of the elliptical rotor major axis with respect to the reciprocating shaft coupling enabling time-varying power to be delivered to the mechanism.

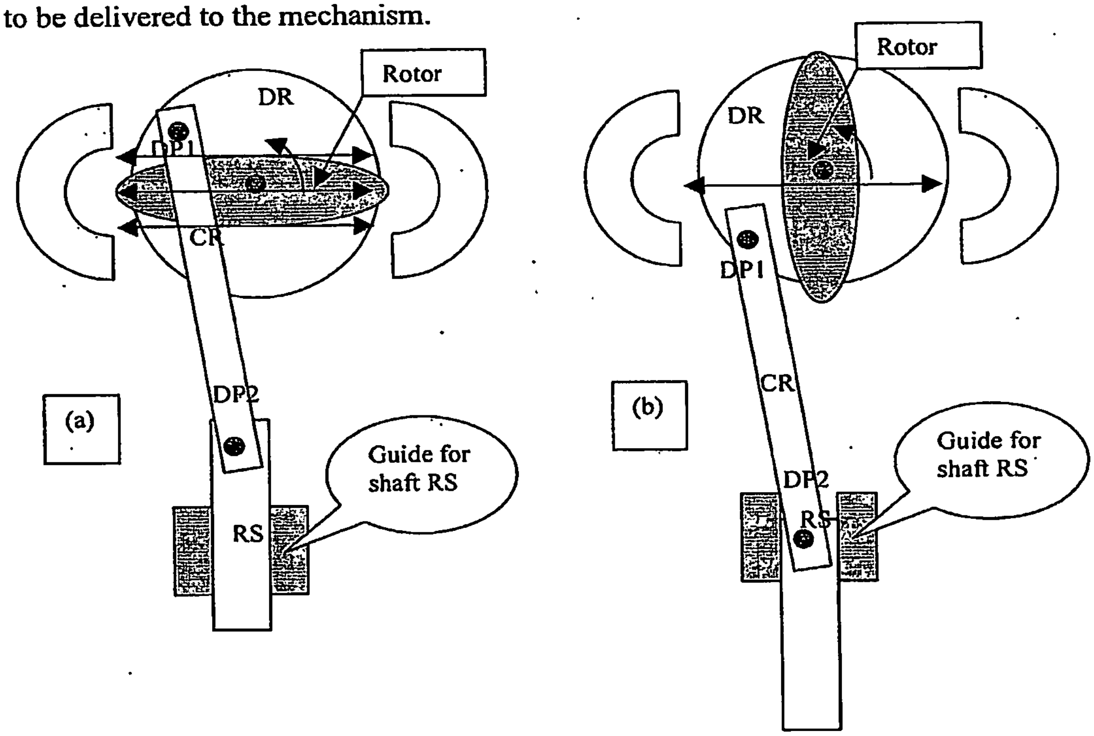


Figure 24: Power Control for a Reciprocating Mechanism (a) Maximum Force/Torque position (b) Minimum Force/Torque Position

In Figure 23 (a), the position of the mechanism is such that the elliptical rotor is aligned parallel to the main flux path, maximizing torque delivered to DR, and hence force to reciprocating shaft RS. A quarter rotation later, the elliptical rotor is perpendicular to the main flux path, minimizing force delivered to RS. Thus the force/speed/position/timing

of the shaft RS can be made variable, by appropriately designing and orienting the elliptical rotor, with respect to the mechanism. The force/torque variation can be made customizable, and asymmetric at time of use, by the programmable ferromagnetic inserts shown in Figure 10 (c) and (d) (Section B)).

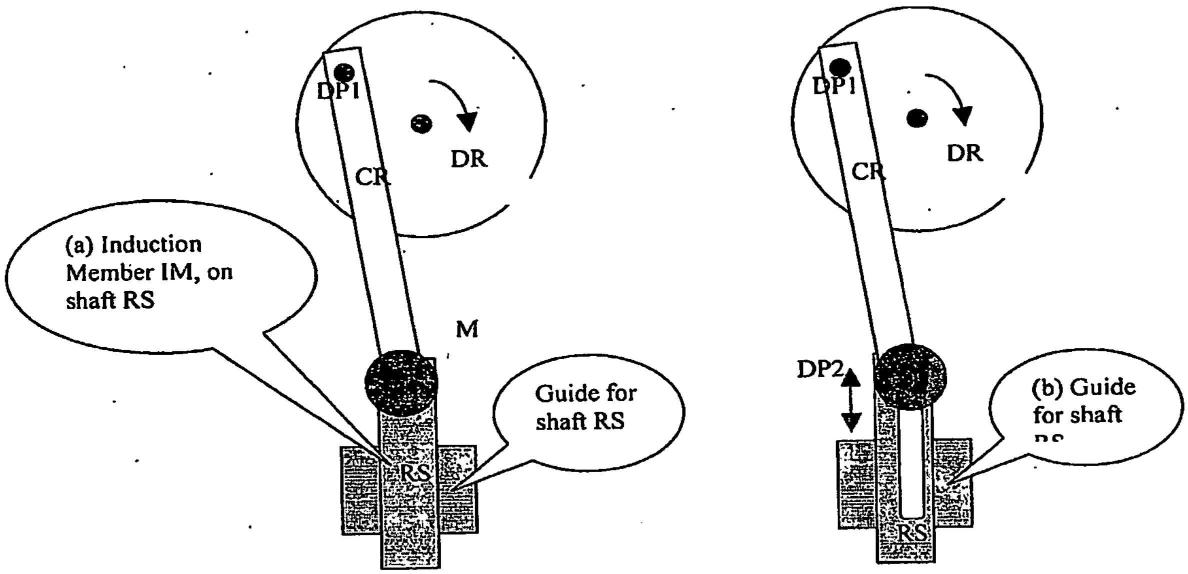


Figure 25: Power Transmission Control For a Reciprocating Mechanism.(a) The drive pin DP2 is omitted (or modified), and auxiliary constraints keeping connecting rod CR in the vicinity of reciprocating shaft RS are present. Magnet M (or Magnets M) are attached to CR. Inductive force is produced in RS, due to slip between CR and RS. (b) Modification of drive pin DP2. A slot is cutout in RS, in which DP2 can slide. The slot serves to constrain CR to be in proximity with RS. No vertical force is transmitted through the slot. Vertical force is due to induction in RS due to field from magnet M (or magnets M)

An embodiment of Power Transmission Control attaches magnet M (or Magnets M as per Section A) to CR in the vicinity of the drive pin DP2. The drive pin DP2 is omitted (or modified), and auxiliary constraints keeping connecting rod CR in the vicinity of reciprocating shaft RS are present. The reciprocating shaft RS incorporates an induction/hysteresis member of various kinds, as per Section A. Exemplarily, a slot is cutout in RS, in which DP2 can slide. The slot serves to constrain CR to be in proximity with RS. No vertical force is transmitted through the slot. Vertical force is due to induction in RS due to field from magnet M (or magnets M). Note that magnet M can be on RS, and the induction member on CR, instead of the configuration shown, or on both.

Electromagnetic force is produced in RS, due to induction caused by slip between CR and RS. ***Reciprocating forces of frequency less than a bandwidth B depending on the strength of the induction, will be transmitted between CR and RS. B, the 3dB bandwidth of force transmission, is a function of the magnetic circuit, and can be calculated by well-known techniques of electromagnetics and dynamics***. One major advantage of inductive power transmission control is fail-safeness. If RS is prevented from motion due to an obstacle, excessive guide friction, etc, the rest of the mechanism can continue to operate, maybe moving other parts which are still operating. The transmitted force will increase, because the slip is maximum when RS is stationary, but the mechanism will *not stall or "jam".*

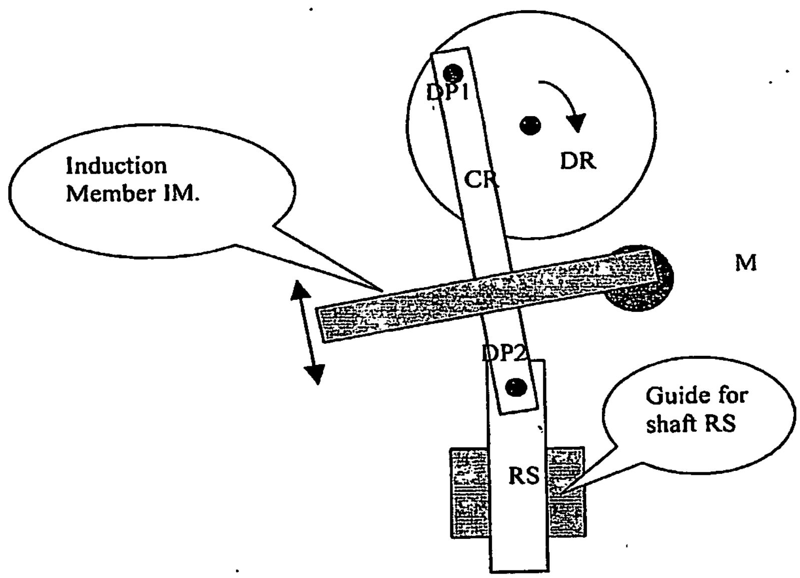


Figure 26: Reciprocating mechanism with Load control

Figure 26 shows an embodiment of Load Control, which attaches an induction member IM to connecting rod CR. This induction member is a conductive strip IM, whose geometry, dimensions (length, width, thickness), are determined to obtain the desired braking force, as per the description in Section A. The induction member IM may be identical to the connecting rod CR, and may also be any of the pins DP1 or DP2. Instead of an induction member, a hysteresis member, or automonous sources of magnetic flux (e.g. magnets) can be used, as per Section A.

At a desired position of this reciprocating mechanism, the conductive strip IM passes over a magnet M (or magnets M as per Section A), developing opposing electromagnetic force (inductive), which slows the mechanism down. This causes the mechanism to expend more time in those positions when the strip IM is over the magnet M, resulting in control of the timing of the trajectory of the whole assembly, in particular reciprocating shaft RS (exactly analogous to the discussion for the timing control induction member on page 36). This is further illustrated in Figure 27 below.

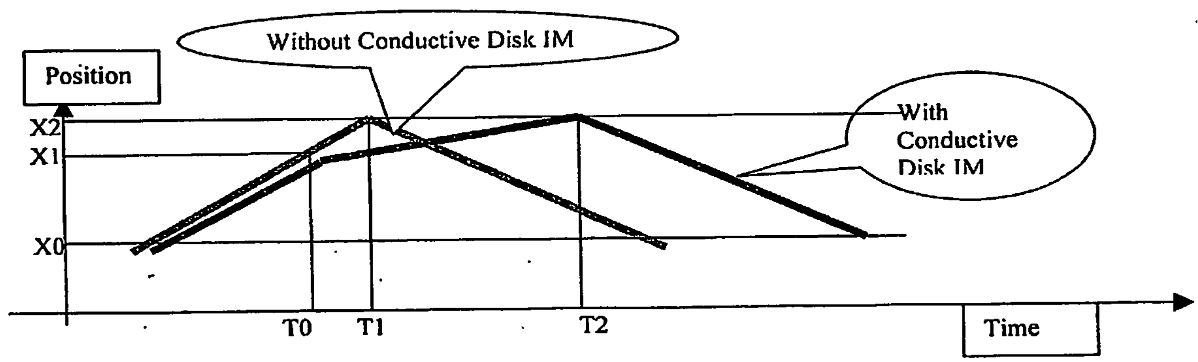


Figure 27: Mechanism Timing Change by induction force

Figure 27 shows the waveform of the position of the reciprocating shaft RS over time, which periodically oscillates between positions X0 and X2, via intermediate position X1. In the absence of the conductive strip IM, the mechanisms goes from position X1 to X2, in a short time between T0 and T1. In the presence of the conductive strip, the time to go from position X1 to X2 is lengthened to the interval between T0 and T2, thus "flattening" the waveform of position with time. Clearly arbitrary time waveforms can be obtained, using a suitable number of induction/hysteresis members like IM, a suitable number of magnets, and appropriate geometry and dimensions (length, width, thickness), material type, and material solidity, slottedness, or perforatedness as appropriate (as per the discussion in Section A). The force can be programmably generated, by providing slots for both induction/hysteresis members like IM, and magnets M, so that the timing behaviour of the mechanism can be changed as required (as described in page 39).

All three forms of control to this mechanism, Power Control, Power Transmission Control, and Load Control, admit of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnet/induction/hysteresis members of different geometry, etc. as per Section A. Note that with hysteresis members, and multiple autonomously magnetic interacting members, the mechanism has preferred rest positions, which have to be accounted for during design (Section A).

In the rest of the examples, we shall discuss primarily Load Control for brevity, but Power Control (for powered devices) and Power Transmission Control are equally applicable, in a manner similar to this example.

2. 4-BAR LINKAGE WITH PERMANENT MAGNET ON ALL LINKS.

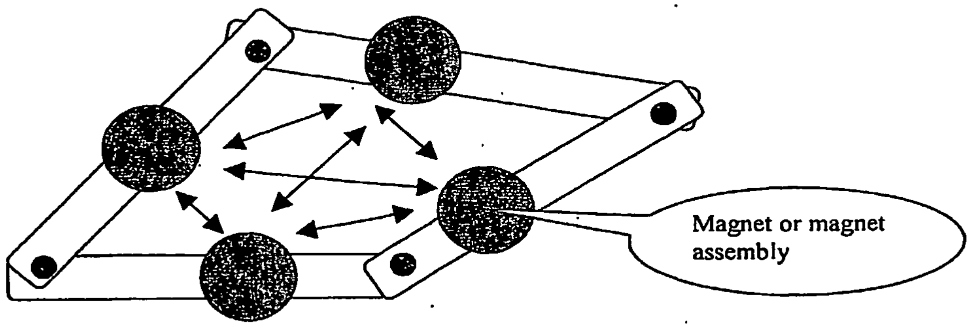


Figure 28: 4-bar linkage with magnetic interaction between links, with capability to form mechanical logic.

This Load control example illustrates the use of multiple autonomously magnetic interacting members, to control mechanism statics and dynamics. Figure 28 shows a 4-bar linkage, using magnets (permanent or electromagnets) placed on the mechanism links/pins, as multiple autonomously magnetic interacting members, and their mutual interaction determines

1. Preferred Rest Positions of the Mechanism. ***<u>There can be multiple rest positions, yielding monostables, bistables, as well as multi-valued mechanical logic</u>***. Such mechanisms can be cascaded together to form logic functions, analogous to electronics.
2. The dynamics, due to the coupled electromagnetic attractive/repulsive forces, as a function of position.

The forces due to magnets (which can be positioned as required to exert forces) can be used in conjunction with induction/hysteresis members as per Section A, allowing extensive customizability of mechanism statics (rest positions), and dynamics.

A preferred embodiment makes the connecting pins and their housing magnetic. This has the advantage that the air-gap does not change as the mechanism moves, which keeps the maximal forces invariant as the mechanism moves. Note that the magnets may be attached to circular disks attached to the pin and the housing, to obtain more torque due to the larger radius. The magnets may also be attached to similar variants of different geometry, all keeping air-gaps close-to constant.

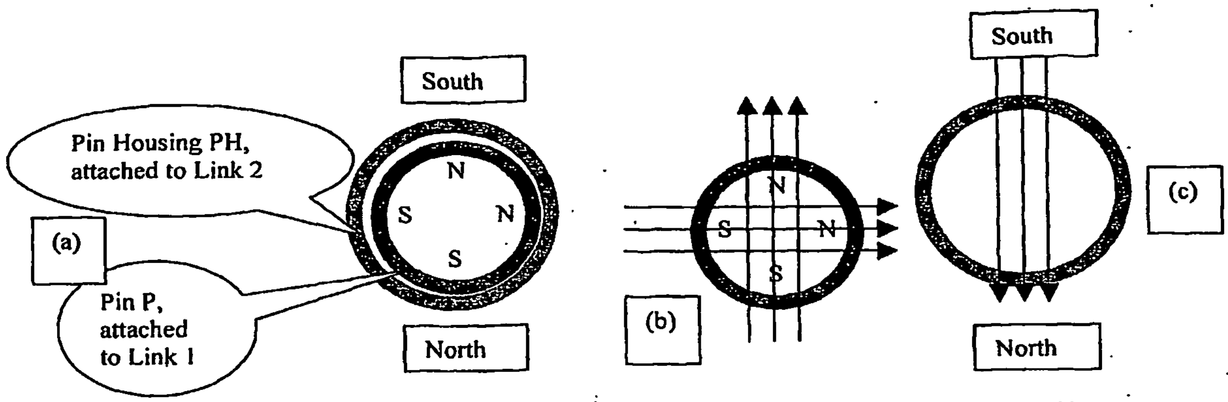


Figure 29: Magnetization of Connecting Pins and Housing (a) Pin and Housing together (b) Magnetization of exemplarily hollow pin (c) Magnetization of Housing

Figure 29 (a) shows a (hollow) pin P connected to a first link (say link1), rotating in a housing PH connected to another link, say link2. The pin P is magnetized as shown in Figure 29 (b), with two North and two South Poles, while the housing has a single North and a Single South Pole. This magnetization may be realized by attaching magnetic material to the pins themselves, or making the pin of hard magnetic material, and magnetizing it, and other means well known in the art [4][5]. Additionally, there may be an auxiliary sleeve of nonmagnetic material enclosing pin P, to prevent it from sticking to the stator due to magnetic attraction.

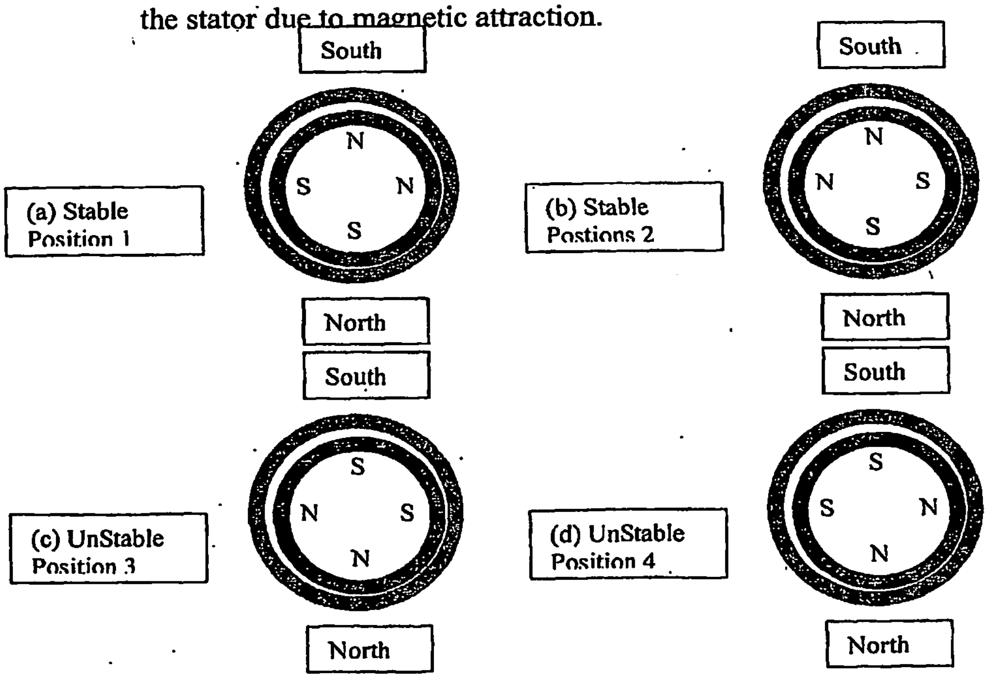


Figure 30: Two stable (a), (b) and two unstable (c), (d) positions of magnetic pin and pin housing, offset by one quarter revolution each.

Figure 30 shows the pin and its housing in two stable states [(a) and (b)], where the north pole of the housing impinges on the south pole of the pin, and two unstable states [(c) and (d)], where the north pole of the housing is close to the north pole of the pin. All these states are offset by one-quarter revolution. Hence in the mechanism, link1 and link2 would preferably occupy (a) and (b) positions relative to each other. Clearly, some or all of the pins and their housings can be thus constructed. When the apparatus is assembled, the interaction of all these magnetic forces will determine the rest position of the apparatus. The sizes of these forces can be controlled by suitable design and magnetizations of the pin and its housing, as per Section A. Suitable design and orientation of such magnetized pins and housings can be used to realize any desired rest-positions of the mechanism. The dynamics of the mechanism can be controlled, for example, using induction members for induction based Load Control, to slow down "ratcheting" between the states.

- In general, rest states can be controlled by any of the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, hysteresis/magnetic members of different geometry, etc. as per Section A. If there are K desired rest positions for the for the apparatus, then the magnets in the pins will have O(K) poles. In a simple design for a mechanism with one degree of freedom, only one pin is magnetized with K North-south pole pairs, the housing has a single N-S pair, and the rest are non-magnetic. A simple algorithm to determine the pole locations is to place a N-S pair on the pin, aligned with the N-S field on the housing in each desired rest-state. In general, the resulting N-S pairs may be close together, in which case, multiple pins can be magnetized, with each pin having rest-positions at a subset of the rest-states of the whole mechanism. Multiple pins/housings may be magnetized in more complex designs, possibly with higher holding forces, for both single-degree of freedom mechanisms, and multiple-degree of freedom mechanism.

- In general, dynamic motion between two states can be controlled by any of the variants using possibly induction/hysteresis effects, multiple autonomously magnetic

interacting members, induction/hysteresis members of different geometry, etc. as per Section A.

Power Control (if it is powered) and Power Transmission Control can also be applied to this mechanism. Exemplarily, one of the pins could be driven by a motor with an ellipsoidal rotor, for power control. One or more pins can be omitted, and replaced by frictionless/non-force transmitting constraints, together with induction members and magnets similar to Figure 25, for Power Transmission Control.

Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnet/induction/hysteresis members of different geometry, etc. as per Section A.

Clearly the ideas can be applied to more complex mechanisms like the Watt Chain, the Stephenson Chain[13], Chebychev's walking mechanism[14] (exemplarily, here the rest states can be designed to fold the legs in a crouching position). This is clearly a generalization of well-known stepper motors, to create stepper mechanisms (especially if there are powered coils in addition to permanent magnets on the pins).*

Many useful apparatus can be built using such mechanisms, e.g., tables to hold objects in moving environments (e.g. a bottle holder for a car), read head rest-positioners in disk drives, a extendible door etc. ***An advantage of this invention is that the motion between the states is noiseless, unlike ratcheting alternatives well known in the state of art***.

* Excitation of the coils "steps" the mechanism

3. SCREW MECHANISM

Consider the screw mechanism in Figure 31, utilizing Load Control. Magnet M or magnets M (with configurations as per Section A), generate inductive torque only if the solid portions of the induction members is angularly positioned over magnets M, thus allowing control of timing of reciprocating joint translation and angular motion.

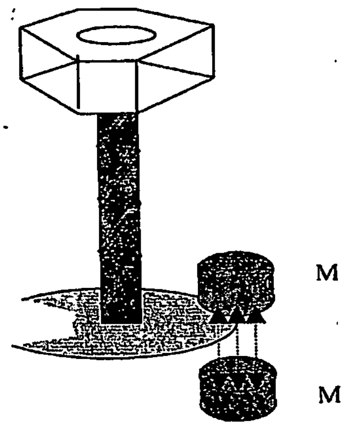


Figure 31: Screw mechanism with controllable possibly non-uniform torque.

Power Control can also be used, with a motor with an asymmetric rotor driving the screw, analogous to that in the reciprocating mechanism (Figure 24, in Section E1).

Power Transmission control in this case can be an induction clutch attached to the screw, of several designs well known in the state-of-art. The key generalization of the state-of-art is in the use, in that reciprocating motion is transmitted, and the force transmission drops off at high reciprocating frequencies, beyond the bandwidth of the transmission of the induction force, which can be calculated by standard techniques of electromagnetics and dynamics (Section E1).

Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnet/induction/hysteresis members of different geometry, etc. as per Section A.

4. EJECTOR/LATCHING MECHANISM

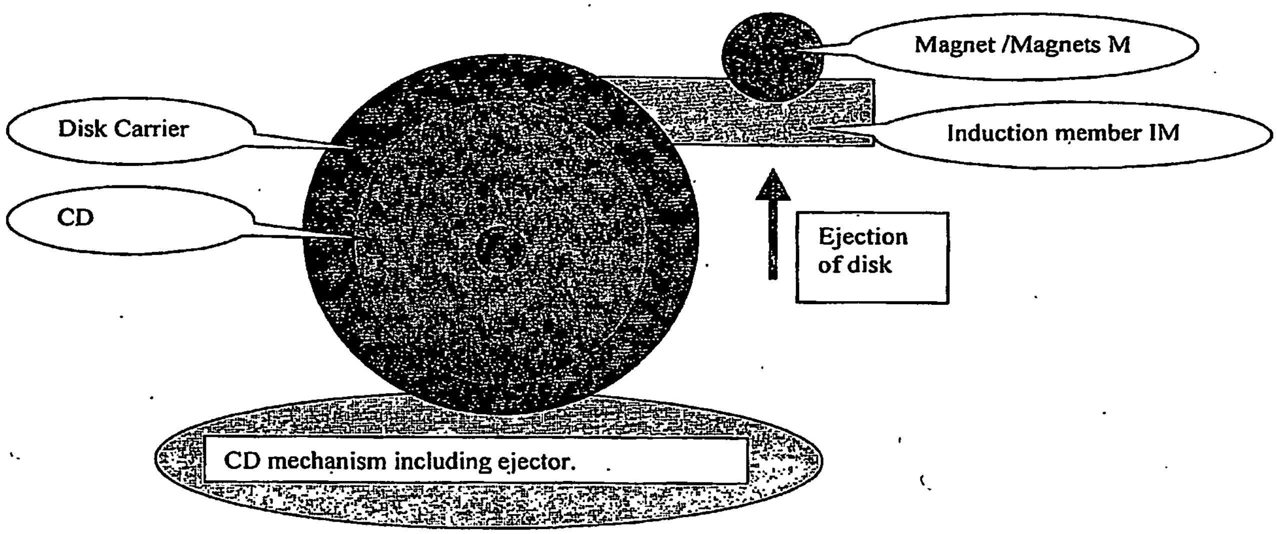


Figure 32: CD mechanism incorporating induction braking to prevent violent ejection

The invention can be applied to controlling the ejection speed in ejectors (latching speed in latches), using induction/hysteresis/forces, or forces between multiple magnets. This is very useful in floppy/CD/DVD drives to prevent floppy disks/CD/DVD's from being violently jerked out during the ejection process, tape/VCR players to prevent the tapes from being violently jerked out, etc. In addition, the potential to control mechanism speed can enhance reliability of these devices.

Figure 32 shows such an embodiment, where an induction member IM in proximity with a magnet, applies braking force to the disk, or the disk carrier, during ejection. Force is also applied during insertion, but that is typically much less, due to the low insertion speeds. The high speed during "latching" of the CD, can also be controlled using the same or additional induction members and/or magnets. For floppy drives/VCR's, the induction members can be attached to the mechanism members themselves, as carriers are not typically used for these devices. In summary, the speeds of the entire mechanism, and all attachments (disks, tapes, etc), can be regulated to enhance safety and reliability.

Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnet/induction/hysteresis members of different geometry, etc. as per Section A.

5. AN UNCONSTRAINED MECHANISM: CARROM, BILLIARDS, AND SNOOKER ENHANCED WITH MAGNETICS

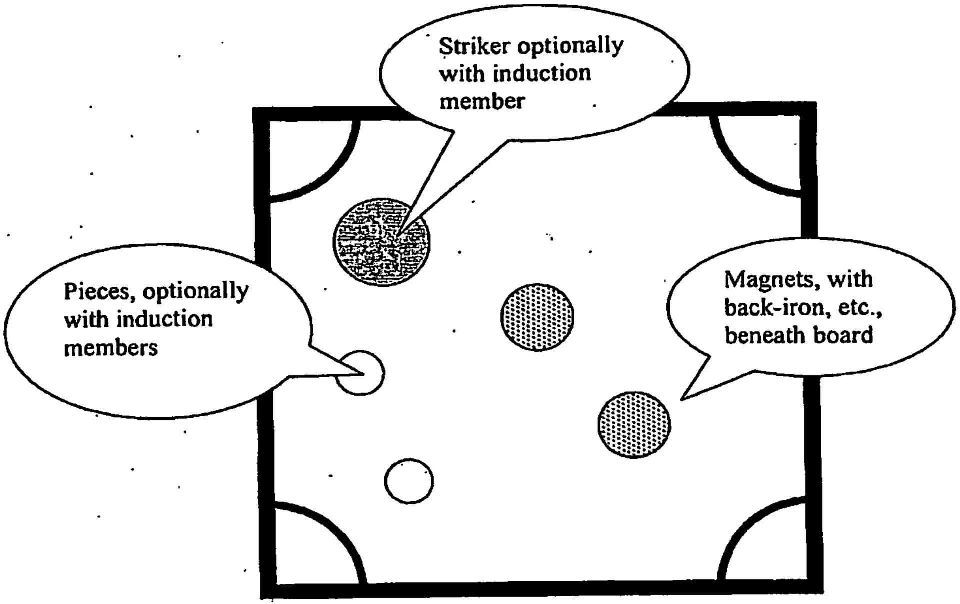


Figure 33: Top View of Carrom Board, showing magnets beneath board, and induction members in the strikers and/or pieces.

The carrom board shown in Figure 33, has magnets placed beneath the board, and strikers and pieces optionally with induction members inserted. By suitable design (e.g. hollowing out the strikers and pieces), it is possible to have their mass be identical to that of a piece without an induction member. The collection of strikers, pieces and magnets constitutes a mechanism, without any path constraints, other than the limits imposed by the sides of the board. The forces exerted on the induction members by the magnets, will influence the path of the strikers and/or the pieces, and add variety to the game.

Variants include placing magnets on the strikers and/or pieces, and induction members below the board, etc. The sides of the board can also be magnetic, or have induction members. Magnets/and or induction members can also be placed above the board, using auxiliary supports. The position of the magnets can, in an embodiment, be selectable by the players at the start of the play, or optionally changed during play. The magnets and induction members can be of various kinds, as described in Section A. Appropriate mechanisms like strong adhesives, strong enclosed mechanical support, etc. may be

necessary to make the generally brittle magnetic materials appropriate for pieces and strikers. Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnet/induction/hysteresis members of different geometry, etc. as per Section A.

Power control in such devices clearly is human skill. Power Transmission Control can be applied, for example, in utilizing contactless striking by induction. In such cases, the magnetic striker does not hit the piece, but glides by it, generating inductive force to move the piece.

It is evident to those of ordinary skill in the art, that the same idea can be applied to billiards and snooker, and in general any similar board game.

6. EXTENDIBLE TETHER WITH INDUCTION BRAKING

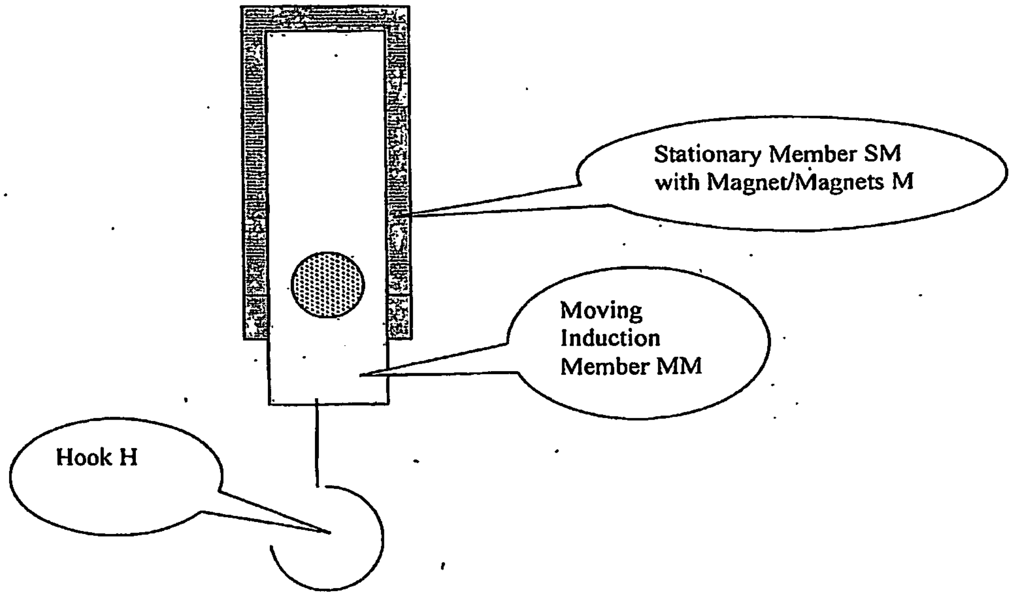


Figure 34: Extensible Tether with Induction Braking (front View)

Figure 34 shows an extendible two piece tether, with a stationary member SM having one or more magnets M (together with flux return paths not shown, following Section A). A moving induction member MM is attached to a hook H, to which a weight can be attached. Induction braking prevents excessively rapid fall of the weight. Several such tethers can be connected by hinges together, to form a pseudo-elastic "cord", which extends slowly. The geometry of the stationary member SM and moving members MM can be other than shown, including telescoping tubes, etc. In one variant, stationary member SM is a flexible ferromagnetic tube which is magnetic in the interior, and the moving member MM is a rod, or tightly coiled wire of copper, which is braked by induction effects.

A variation of this is an optical workbench, which is suspended using several such tethers, together with springs to limit the maximum amount of motion allowable. The induction forces will reduce the optical bench vibrations.

Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnets/induction/hysteresis members of different geometry, etc. as per Section A. With hysteresis members and multiple autonomously magnetic interacting members, rest positions emerge, which can be profitably used. For example, a series of magnets on MM can interact with SM's magnets, creating a sequence of magnetically latching positions for the mechanism. In effect a linear contactless noiseless ratcheting mechanism results.

7. MAGLEV and INDUCTION BRAKING FOR AN AIRCRAFT

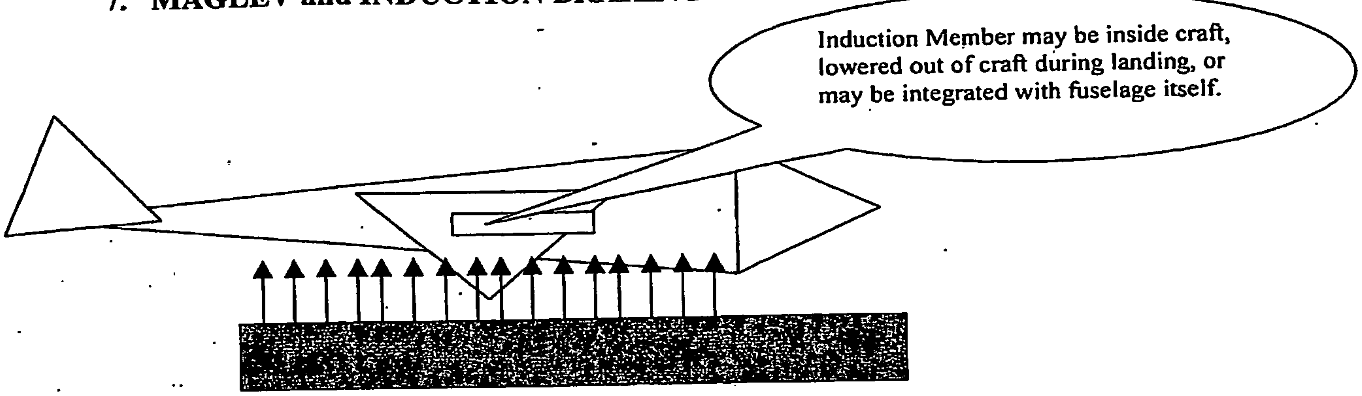


Figure 35: Airplane with Maglev, Magnets on Ground, and Induction Member on aircraft.

Figure 35 shows an aircraft utilizing magnetic levitation for takeoff and landing. The system functions as a Maglev during takeoff, and as an electromagnetic brake during landing. The induction member can be a mesh of conductive material, in the fuselage itself. It can also be the fuselage itself, provided the aircraft aluminum is properly alloyed to have sufficient conductivity also. The field can be generated by a set of superconducting magnets under the runway, arranged to have the field impinge on the craft above. The direction of the field will not be exactly vertical, in general. In such cases, we have to use only the vertical component of the field, to prevent other undesirable disturbances to the aircraft. This can be ensured by choosing an induction member whose effective conductivity is asymmetric along different directions (due to choice of material, geometry, etc.), and which is oriented to direct the current perpendicular to the aircraft fuselage, roughly parallel to the wings.

If the magnetic fields can be generated over 100-200 meter dimensions, ultra-reliable braking can be achieved due to simplicity of operation, compared to conventional friction brakes, air brakes, etc.

Magnetic levitation principles can be used in takeoff as follows. High strength superconduction magnets placed on the plane can induce repulsive forces in a large induction member beneath the runway, generating additional lift. A moving magnetic

field on the runway, generated by sequentially exciting a series of superconducting magnets on the runway, can induce lift on the aircraft fuselage. In principle, the aircraft can take off and land without power.

A variant of this is an "invisible parachute" for an aircraft. The fuselage can be arranged to have induction members appropriately shaped and oriented. If the aircraft is to braked for any reason, an external magnetic field can be created in the aircraft's path, causing induction braking. We note that, due to the high speed, large forces can be generated by quite modest magnetic fields, exemplarily 0.01 Tesla or less (about 200 times the magnetic field of the earth). Such low strength fields over large regions, can possibly be generated by very large superconducting magnets placed on "rescue aircraft". Note that the induction force is omnidirectional, and will act even when the aircraft is loosing altitude (it will act to slow down descent).

Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnet/induction/hysteresis members of different geometry, etc. as per Section A.

8. Electromagnetic Fully Flexible Manipulator

Another application of our ideas is in electromagnetic manipulators, which pick up ferromagnetic objects and assemble them automatically, using magnetic fields generated by possibly high strength superconducting magnets (or a combination of high strength neodymium magnets and auxiliary coils), and move them to desired positions automatically by controlling the currents generating the fields. Translational motion can be achieved by a field which is translating in the direction, rotational motion (a screw being tightened) by fields which are rotating, etc.

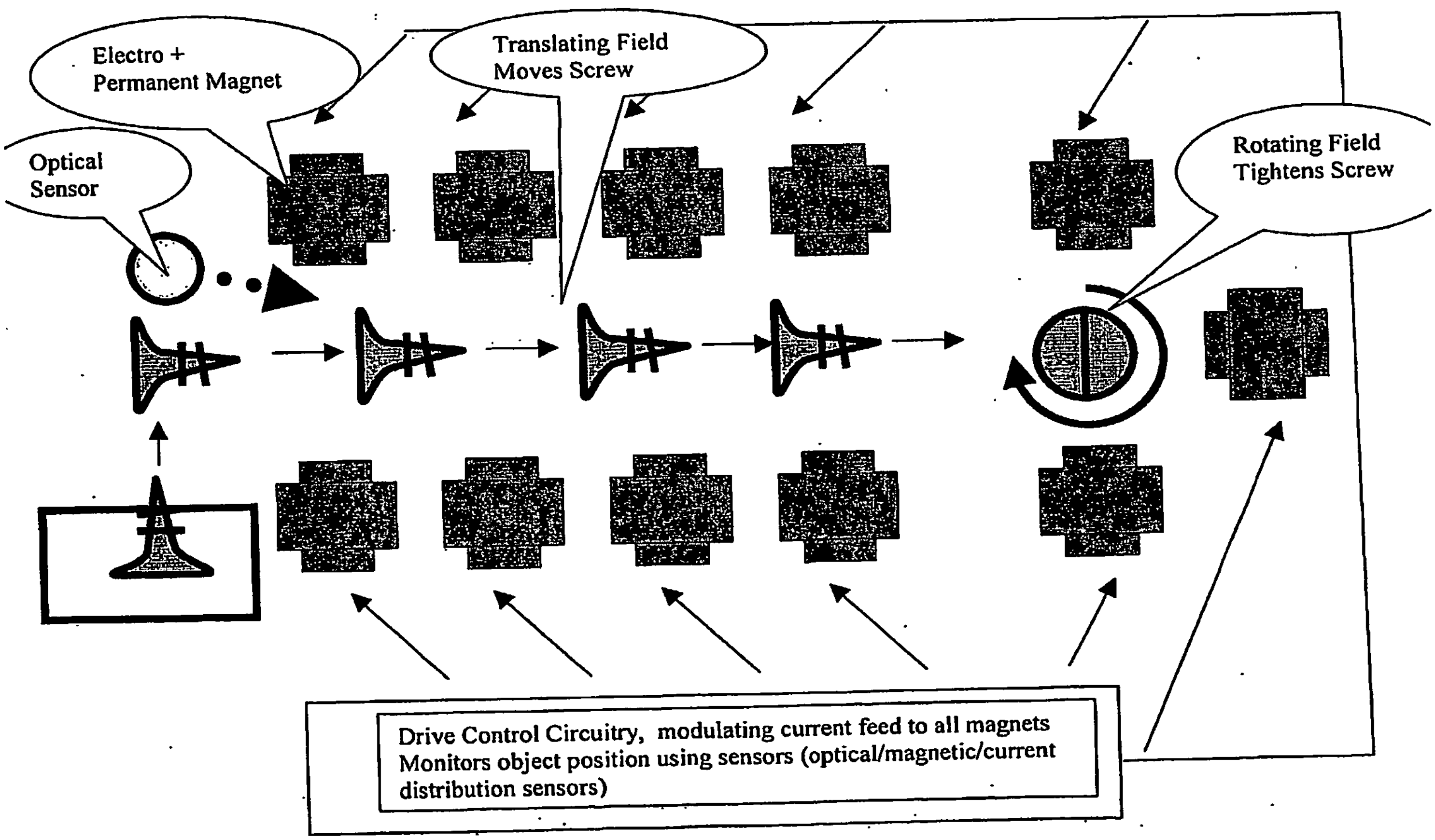


Figure 36: Electromagnetic Manipulator lifting exemplarily screws, and tightening them in object not shown

Figure 36 shows a bin with screws being picked up, moved right by a translating magnetic field, and tightened by rotating magnetic fields, all under the control of the drive control circuitry. The major advantage of this system is that the forces exerted on

the objects being moved and assembled are distributed to some extent throughout the body, minimizing stress/strain at the surface, and enhancing reliability. In addition, controlled torque can be delivered while tightening, minimizing overtightening risk. Finally, the number of degrees of freedom of the manipulator are in principle infinite, since there are no mechanical joints. This can find applications ranging from assembly of small structures, to assembly of high reliability apparatus like aircraft, high-speed trains, etc.

Clearly the mechanism admits of all the variants using possibly hysteresis effects, multiple autonomously magnetic interacting members, magnets/induction/hysteresis members of different geometry, etc. as per Section A.

F. APPARATUS USING THE INVENTION

To illustrate the wide applicability of the invention, we describe additional exemplary apparatus using the ideas outlined in Sections A, B, C, D, and E, including uniform motion control, non-uniform motion timing control, with and/or without user programmability, and motion control in general mechanisms. The ideas can be applied in other apparatus, and the claims extend to them. Specifically, we apply the invention to enhance the functionality of

1. A bubble toy, demonstrating vibrations of minimal surfaces (Figure 37, Figure 38, and Figure 39).
2. A vibration bench, whose vibration velocity profile, and hence vibration spectrum, can be controlled to suit, generating harmonics as desired.
3. A paper dispenser, which is enhanced to prevent excessively rapid rotation of the paper roll, to prevent wastage (Figure 40).
4. A well pulley with an induction brake to prevent the water vessel from dropping excessively fast (Figure 41).
5. A display turntable, whose rotation speed can be controlled to provide best viewing to customers/onlookers (Figure 42).
6. A display turntable, whose non-uniform rotation speed profile can be programmably changed to suit, by the user, for best display effect (Figure 43, Figure 44).
7. A lazy-Susan type device, which is enhanced to provide a smooth resistive force to prevent excessively rapid rotation of the device (figures same as display turntable).
8. A rotating doll, whose speed of uniform rotation can be user controlled, or a rotating doll, whose non-uniform rotation speed can be both user controlled, as well whose non-uniformity be user programmed (Figure 45).
9. A rotating Lollipop dispenser (popularly known as "SpinPoP", etc.), having speed control built in, enabling the Lollipop taster to rotate the Lollipop at any desired speed in the tongue (Figure 46)
10. A timing CAM based on electromagnetic force principles (Figure 47).

11. A powered toothbrush, providing very low cost continuously variable speed control to the user (Figure 48).
12. A toothbrush mechanism, which "automatically declutches" at excessively high load.
13. A toothbrush mechanism, whose brushing velocity profile can be controlled to yield maximum user comfort.
14. A toy racing car, where the resistive speed control, is replaced by a continuously variable induction/hysteresis speed control using our techniques.
15. A set of toy racing cars, which can co-operatively/competitively race, based on the attraction/repulsion of high strength magnets on them. Here the rest-states of the set of cars would be convoys of cars with the north pole of one car sticking to the south pole of another car, etc.
16. A set of toy racing cars, racing synchronously, due to magnetic attraction/repulsion.
17. A fan or electric razor, providing continuously variable speed control to the user.
18. An electric razor, providing a shaving profile, which slows down when the blade is beginning to cut, and speeds up after cutting.
19. A drawer, which is enhanced to prevent violently rapid opening/closure, increasing both safety and reducing wear and tear of the unit (Figure 49).
20. Any hinged device, which is enhanced to prevent slamming (Figure 50), including but not limited to
    a. A door closer
    b. A oven door closer
    c. A toilet seat
    d. A suitcase lid.
    e. A lid for a plastic bin.
21. A rotating chair, which is enhanced to have an induction disk in proximity with magnets to avoid rotation "overshoot". Alternatively, the chair could have a non-uniform ferromagnetic hysteresis disk, or a disk with multiple magnets, inducing preferred rest positions in the chair.

[redacted]

22. A coat hanger, and coat hanger rail, which is enhanced to include magnets in either the coat hanger and/or the coat hanger rail, to prevent the coat hanger from occupying undesirable "twisted" positions on the rack.
23. A toilet flush tank, which has a magnet attached at the top, to enable steel napkin holders to be held firmly, and not "slip-off" the tank.
24. A car dashboard, with a magnet attached in the middle, to enable ferromagnetic objects to be conveniently held in place, and not "slip off".
25. A circular pedestal, with a ferromagnetic material on the surface, to which platforms can be attached at various heights/angles magnetically, to hold objects, exemplarily flower pots (Figure 52).
26. A pedestal with a spherical ferromagnetic surface, to which platforms/clips can be attached at various positions, to hold objects e.g. pens, pencils (Figure 52).
27. A magnetic shower attachment device, which has a showerhead attachment with a magnetic base, attached to a ferromagnetic strip on the bathtub. This enables the showerhead to be placed at any desired height. Using a grooved ferromagnetic member projecting from the bathtub enables both the height and angle to be varied.
28. A magnetic wire-clipping device, which has a clip, attached to a magnetic base, to enable wiring traditionally placed on the floor to be conveniently organized and routed at appropriate paths on the walls or the floor, without the necessity to drill holes (Figure 54).
29. Any clothing utilizing a magnetic button, and a metal backing, which enables the appropriate degree of tightness to be achieved, based on the individual's current dimensions.
30. A novel field limiting device, to reduce leakage fields from affecting articles of household use.
31. A bearing, which has built in induction load, to reduce excessively high-speed rotor operation – this is done as per the methods of Section D.
32. A gear, whose speed-torque transmission characteristics can be user programmed, and are not necessarily in inverse proportion (Figure 11).

33. A reciprocating mechanism, which does not "seize", at unexpectedly high load (Figure 25)
34. A Geneva mechanism, with contactless engagement (similar to above).
35. A robotic device, which is "fail-proof", and disengages smoothly in situations that are outside the capabilities of its kinematics (e.g. Figure 25, Figure 28).

While the apparatus will be described primarily using induction forces, they admit of all the variants using possibly hysteresis forces, multiple autonomously magnetic interacting members, magnets/ induction/hysteresis members of different geometry, etc. as per Section A. Predominantly, we shall use Load Control (Section D), but Power Control and Power Transmission Control can also be used for powered devices (Sections B and Section C), and our claims apply equally to those variants also

[redacted]

1. Bubble Vibration Toy, demonstrating vibration of minimal surfaces

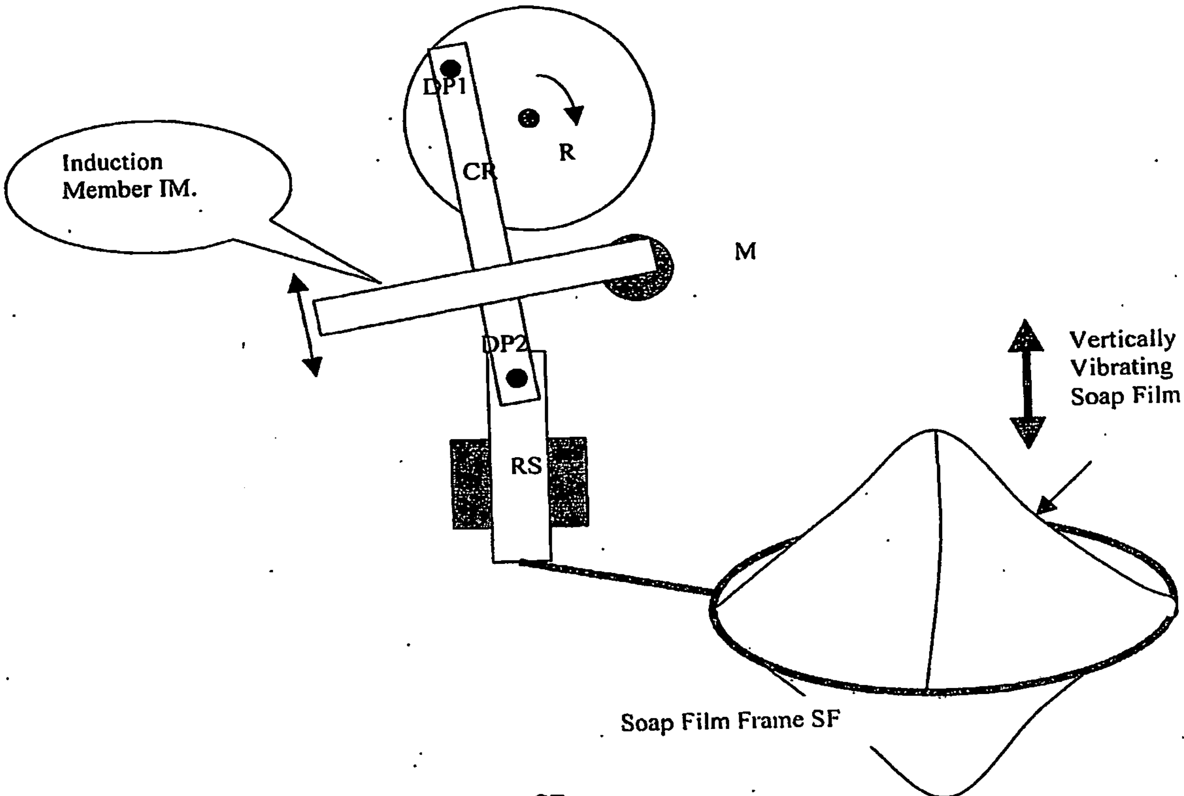


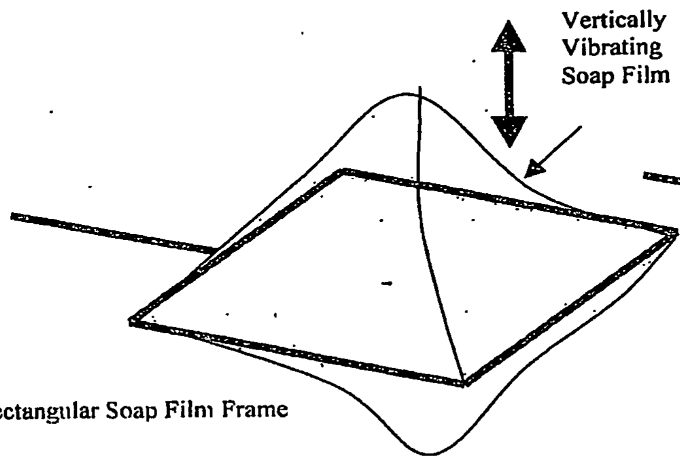
Figure 37 Bubble Vibration Toy, with circular frame SF

The apparatus in Figure 37 shows vibrations of soap films [15][16][17], forming exciting patterns interesting to the children/others. Axle R is driven by an electric motor, whose speed is controlled by magnet M (or magnets M) interacting with induction member IM, as well as possibly other induction members. Soap film frame SF is attached to reciprocating shaft RS, and set into oscillatory motion by it, at a rate controllable by modulating the induction force generated in induction member IM, using any of the techniques outlined previously in (Section A). Instead of IM, other induction members including an induction disk attached to the axle R, can be used and the force/torque controlled following the methods in Figure 13 through Figure 18. When the oscillation rate is equal to any resonant frequency of the soap film, large vibrations can be noticed by the viewer. Instead of a rotating electric motor driving axle R, CR, and then RS, a linear motor [10] may be used to drive RS directly.

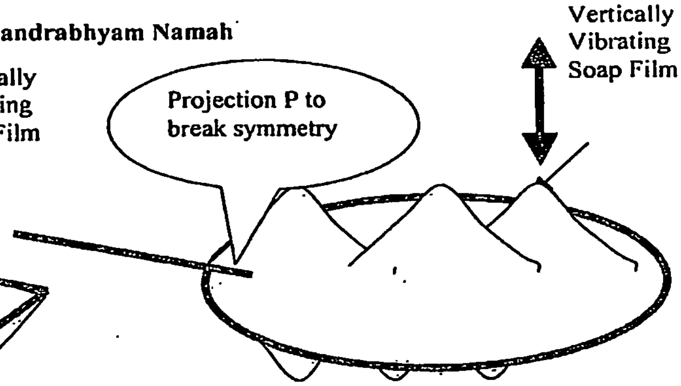
[redacted]

Figure 37 depicts a vibration toy using a circular soap film frame, exemplarily made of thin plastic using injection molding. Figure 38 shows frames of other shapes, square, rectangle (Figure 38 (a)), cube (Figure 38 (c)), octahedral, other 3-dimensional etc. The oscillations can be up-down, sideways, angular (e.g. twisting repeatedly back-and-forth - Figure 38 (d)), and in general a 3-axis translational and 3-axis rotational oscillation. The frame may have symmetry e.g. be a circle, or may have a slight asymmetry (Figure 38 (b)), to break the degenerate nature of resonant modes with respect to angular position, for stable viewing. The frames may oscillate, or be stationary, with auxiliary members of arbitrary geometry attached to the same soap film oscillating (Figure 38 (e)), generating "standing-waves", in the soap film. Multiple frames may simultaneously excite the same soap film, at possibly different frequencies, showing beat patterns. The frames may have multiple portions of different resonant frequency, and changing the oscillation frequency (by controlling the inductive load) will selectively excite different portions, making the viewing interesting (Figure 39).

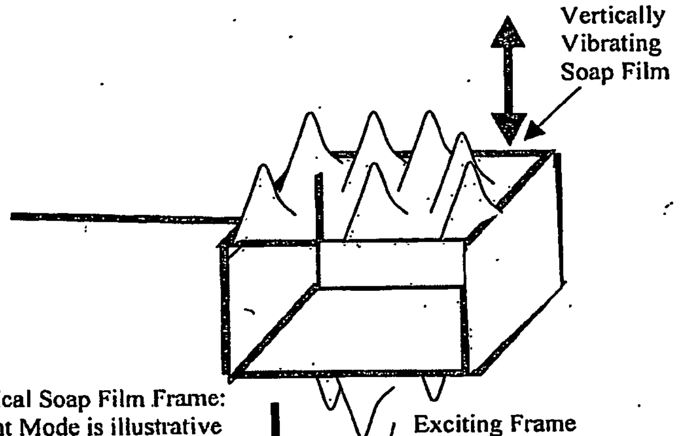
[redacted]



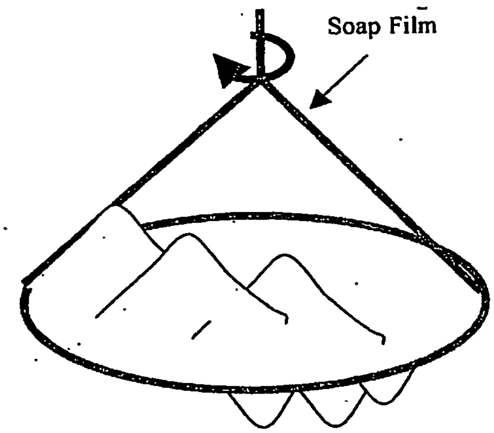
(a) Rectangular Soap Film Frame



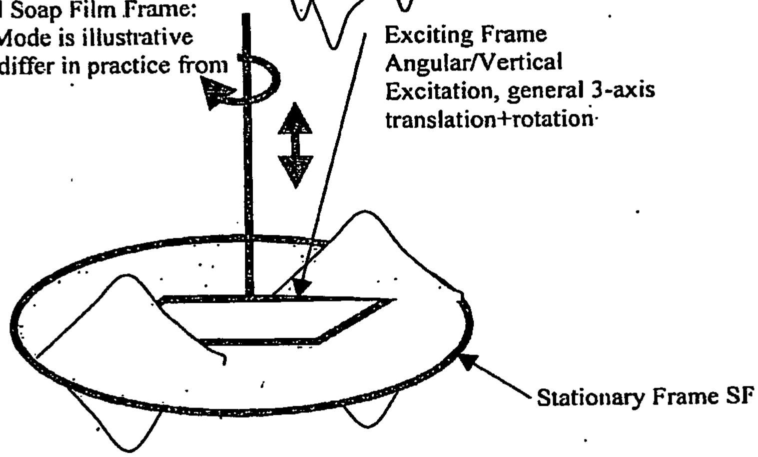
(b) Soap Film Frame SF, showing higher order modes, which are made non-degenerate by projection P from SF, which forces a node (zero motion), and unambiguously determines the angular position of the resonant mode.



(c) Cubical Soap Film Frame: Resonant Mode is illustrative only, may differ in practice from illustration



(d) Soap Film Frame SF, Angularly Vibrating arou
The resonant mode shown is only illustrative, and t
modes obtained in practice may differ from illustra



(e) Stationary Soap Film Frame SF, excited by auxiliary frame angularly vibrating around axis. The shape of the auxiliary frame may be different from illustration. The resonant mode shown is only illustrative, and the modes obtained in practice may differ from illustration. Both frames may be excited. In general one or more frames may be excited using one or more excitation waveforms.

Figure 38: Variants of Bubble Vibration toy, showing different kinds of frames, and different modes of excitation (translation + rotation), possibly using auxiliary frames.

[redacted]

(a) Soap Film Frame Assembly

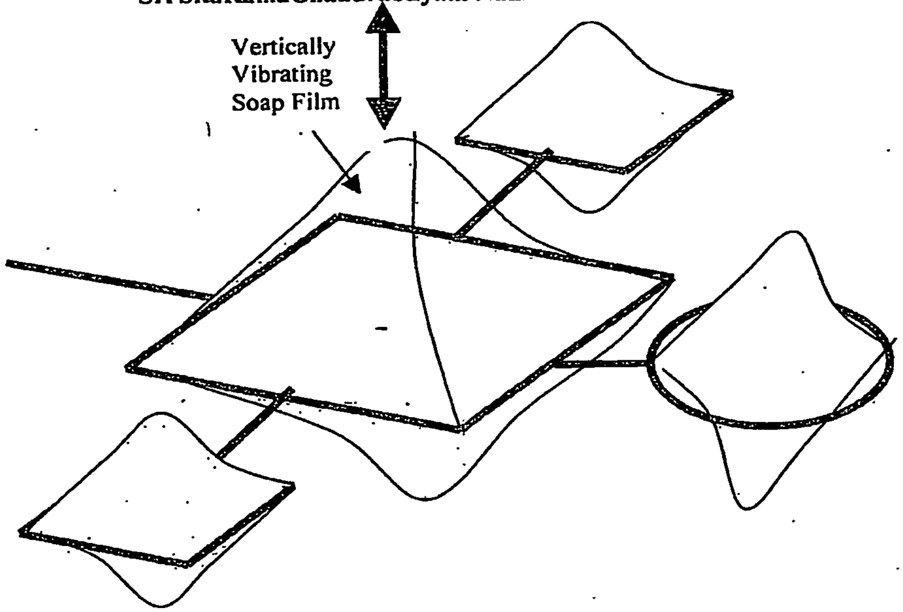


Figure 39 Soap Film Frame Assembly having multiple sections, of different shapes and dimensions, and different resonant frequencies. Changing the vibration frequency, will selectively excite different sections, changing the vibration pattern visible to the viewer.

Many variants of the soap bubble vibration toy exist:

- The means of vibration can be a general mechanism (not just the reciprocating shaft illustrated), and may include multiple moving members, each having in general multiple degrees of freedom, e.g. 3-axis translatory and 3-axis rotational motion.
- The excitation need not be purely sinusoidal, and may have different frequencies exciting different portions of the frame. Cost effective methods of generating motion having arbitrary frequencies have been described in Section E.
- The motion need not be rigid, with the dimensions and/or shape of the soap film frame itself varied using flexible structures for them. Exemplarily, the soap film frame can be a 4-bar linkage, [13][14]. This provides an excellent illustration of parametric oscillations in membranes.
- The soap films can be preferably viewed in strong possibly polarized light, to illustrate the vibrations clearly.

[redacted]

- The whole apparatus can be hand-held, or arranged to be conveniently placed on tables, attached from ceilings, etc, with appropriate lighting arranged.

- The diamagnetic properties of water [10], can be exploited by bringing strong magnets (e.g. neodymium magnets) near the source of vibration, changing the shape of the vibration surface, due to the exertion of diamagnetic repulsive force on the membrane. The magnets can be part of the frame structure itself, arranged in a manner to impinge strong fields on the soap films attached to the surface.

- Instead of soap films, thin latex rubber membranes can be used as the oscillating structures. Alternatively, elastic cords can be used for 1-dimensional vibrations. In either case, the membranes can be loaded at different points to change the resonant behaviour. Moreover, the membrane can be partially and/or completely coated with a highly reflective substance, to create a pleasing lighting pattern, changing with the vibrations of the membrane.

If instead of the soap film frame SF, we have a vibration table attached to shaft RS, ***a vibration testing jig***, whose timing and hence the vibration spectrum can be controlled, is obtained. The spectrum of the vibration can be controlled at far lower cost compared to microprocessor based servos, possibly at the expense of some accuracy and flexibility.

[redacted]

2. **Paper Roll Dispenser with Induction Speed Limiting**

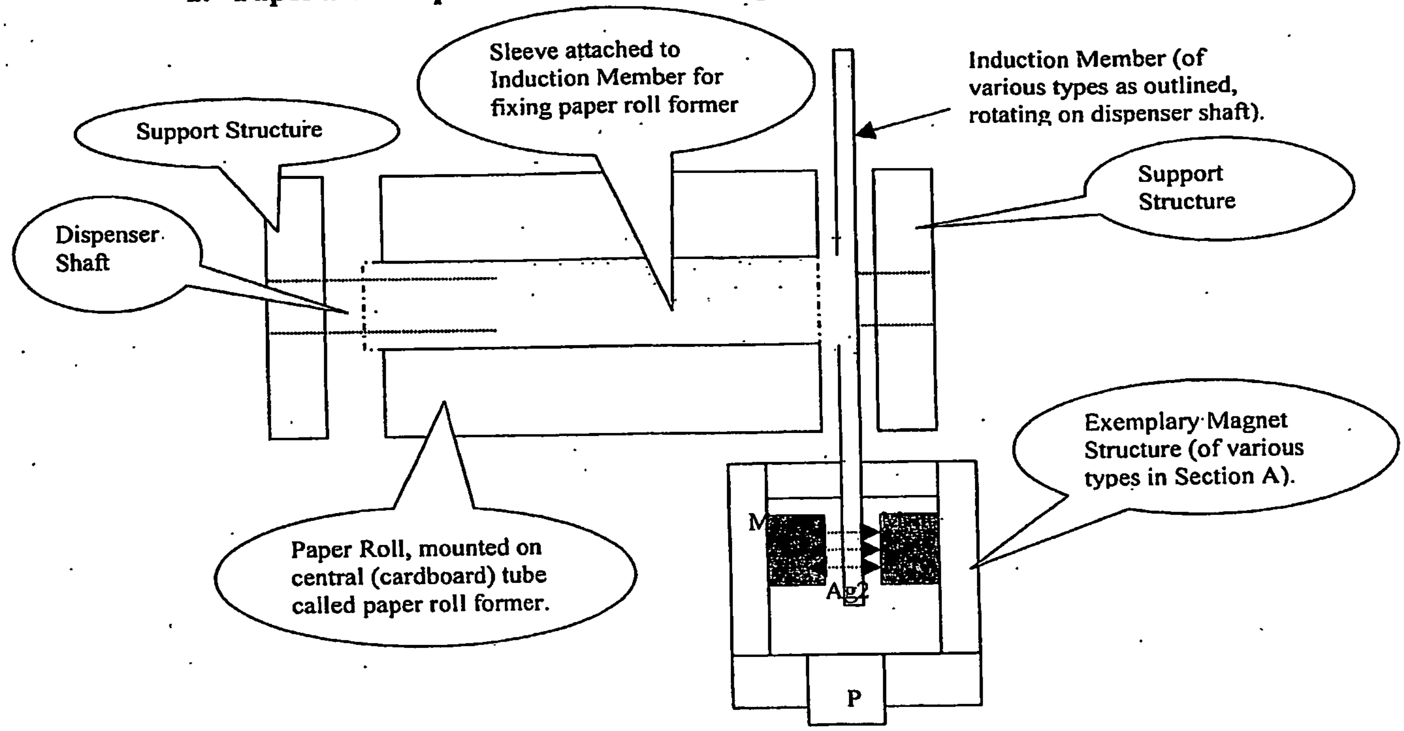


Figure 40: Paper Dispenser with Inductive Speed Control (Exemplary Embodiment)

Figure 40 shows a paper roll dispenser consisting of an induction member revolving on the dispenser shaft, having a sleeve on which the paper roll is mounted using exemplarily a friction fit. The positioning of the magnet structure with respect to the paper roll can be as desired to prevent interference to paper dispensing. Alternative structures can also be used to provide inductive braking force to the paper roll. The apparatus has the following advantages:

1. A large quantity of paper cannot be jerked out of the roll, minimizing wastage.
2. When the roll is spun to release the free end of the paper sheet, the risk of the roll overspinning, releasing a large length of paper is greatly reduced.
3. Easier paper cutting, since the induction disk provides a restraining force.

We note that by using an appropriate induction member, the restraining force can be changed during a cycle (as described in Section A, and Figure 19). For example, we can increase the force to facilitating cutting of the paper, and then reduce it, to facilitate unrolling, etc.

[redacted]

3. Well Pulley with Induction Speed Limiting, and/or attached Dynamo

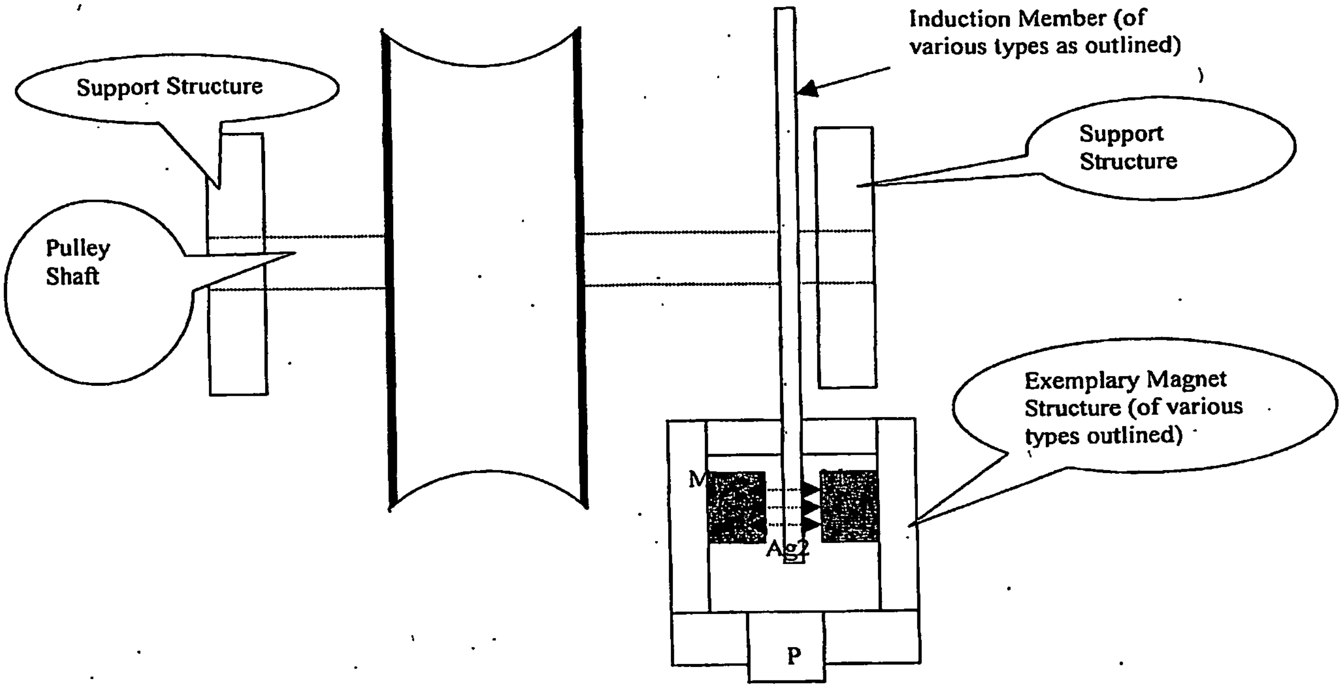


Figure 41 Well Pulley Inductive Speed Control (Exemplary Embodiment)

Figure 41 shows a pulley for a water well, having an induction brake attached to the pulley shaft. The water vessel tied to the rope (not shown for clarity), is restrained from dropping excessively fast into the well, by the induction brake shown, designed as per Section A. This is especially beneficial, to prevent living creatures in the well from being hurt by excessively high speed impact of the water vessel, as well as to prevent damage to the water vessel itself, by impact on rocks, etc, on the water floor, especially during dry seasons. Additionally, the potential energy of the water vessel can be harnessed by converting the induction brake into a dynamo.

[redacted]

4. Rotating Display Turntable, with Variable Speed Control

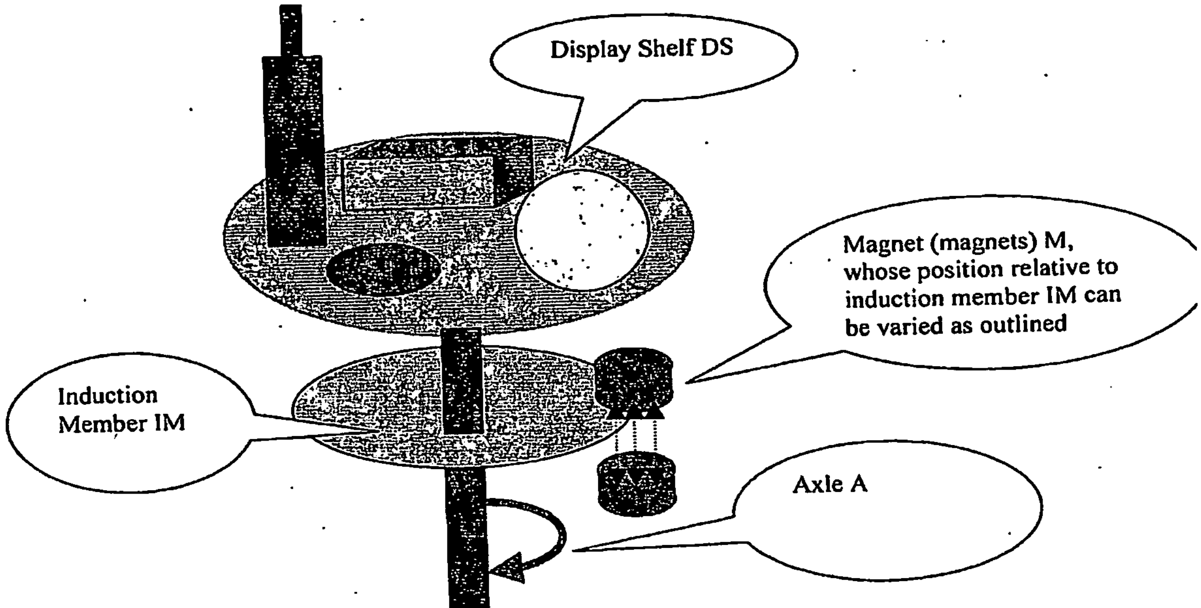


Figure 42 Rotating Display Turntable, whose speed can be controlled using induction device.

Figure 42 shows an exemplary display turntable, where a prime mover (exemplarily an electric motor, not shown), drives axle A, possibly through a gearing mechanism. An arrangement of magnets M, inducing eddy-currents (or hysteresis effects), in induction member IM, enables the speed of rotation of the display shelf DS, to be controlled as desired. The configuration of the induction member, and magnets can be varied as described in Section A.

This apparatus has the following advantages

(a) The rotation speed can be changed in a smooth manner, using methods outlined in Section A, B, C, and D. Indeed, the customer/viewer can be given control to vary the speed to suit.

(b) The display can be directly driven by a motor, without a gear train, provided sufficient induction force is generated by the magnets and induction member.

Without a prime mover (display moved by hand), we get a Lazy Susan turntable, and the claims apply equally to that apparatus.

[redacted]

5. Rotating Display Turntable with cutout, and variable timing control

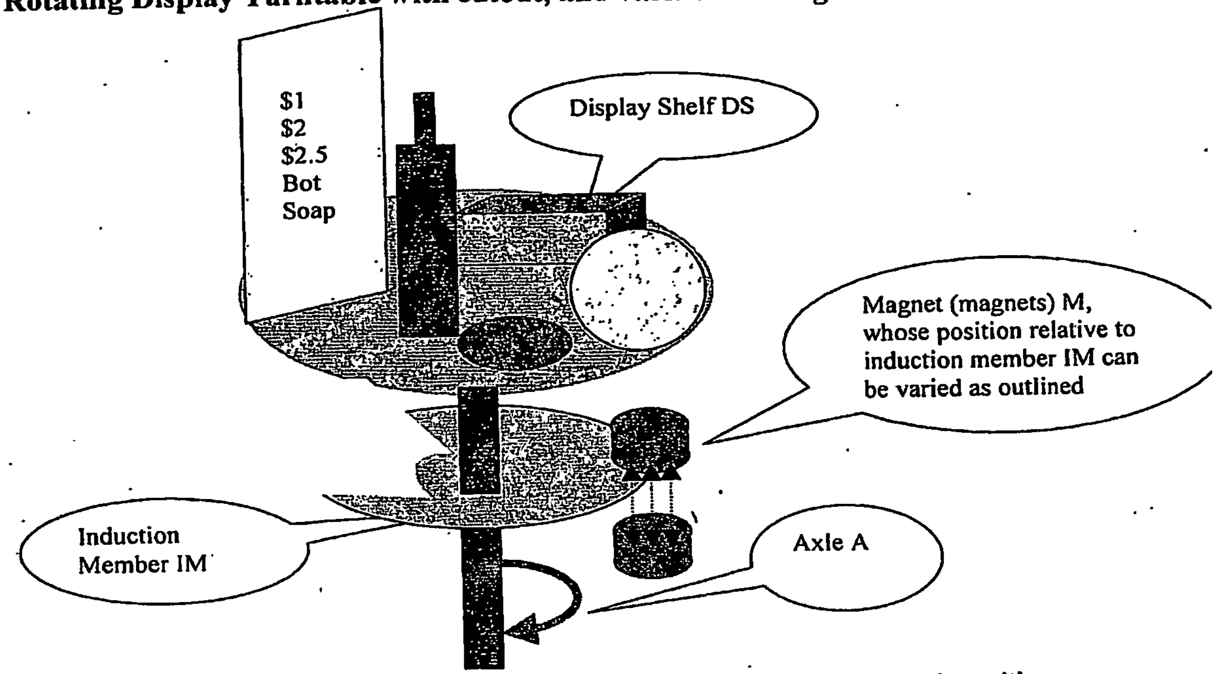


Figure 43 Rotating Display Turntable, whose speed can be controlled using induction device, with cutout.

In Figure 43, the display turntable has an induction member with a cutout, which enables quick "return" of the display objects, from positions where they cannot be conveniently viewed. Figure 43 shows a case where we have a price sheet behind the objects. When the back of the price sheet appears in front, the display turntable turns fast, to maximize the amount of time the viewers (assumed to be in front) are able to view the displayed items. The induction member can of course have different cutouts, possibly multiple, with varying thickness, slots, perforations, may be of different materials, etc, as outlined in Section A. Several induction members and magnets of different properties can be jointly used, as also outlined in Section A.

<u>Without a prime mover (display moved by hand), we get a Lazy Susan turntable, and the claims apply equally to that apparatus.</u>

[redacted]

6. Rotating Display Turntable with Programmable cutout

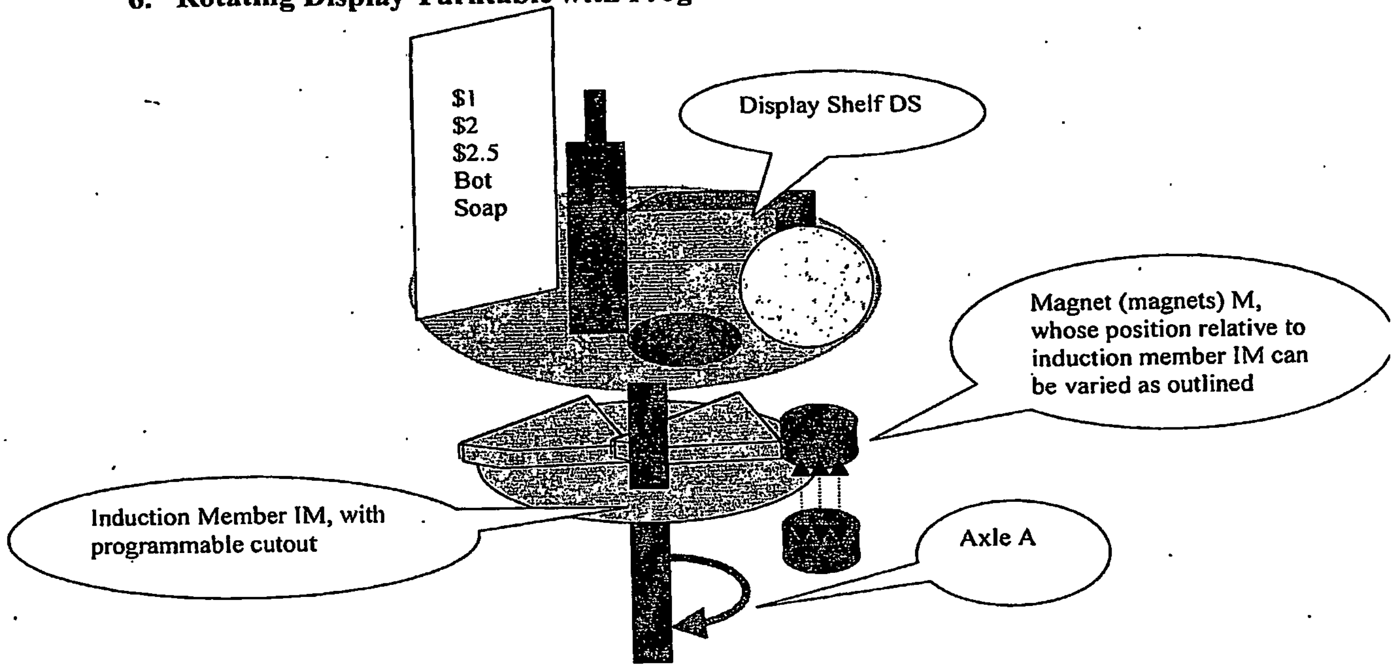


Figure 44 Rotating Display Turntable, whose speed can be controlled using induction device, with cutout, which can be optionally programmable

In Figure 43, the display turntable has an induction member with a programmable cutout as per Section A, Section D, and Figure 23, which enables the quick return, and slow display portions, to be chosen by the user, after positioning the display objects. Thus objects having different angular extents, can be conveniently positioned, and shown for the optimum amount of time each. In general there can be multiple magnets and multiple induction members, some or all of which can be programmably changed as per Section A, Section D, and Figure 23.

<u>Without a prime mover (display moved by hand), we get a Lazy Susan turntable, and the claims apply equally to that apparatus.</u>

[redacted]

7. Rotating Doll

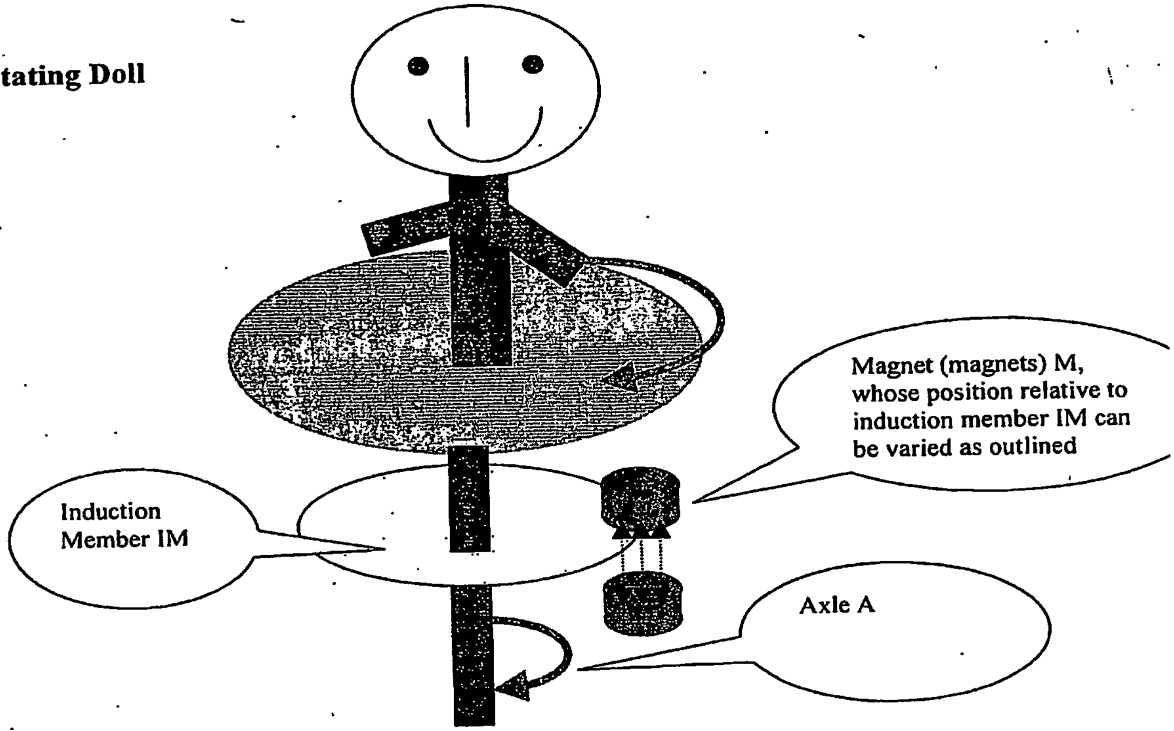


Figure 45 Rotating Doll, with speed programmably controllable, possibly in a non-uniform fashion,

This doll rotates at a speed which can be viewer controlled, using controllable induction force, generated by an induction member interacting with one or more magnets M. The motion may be uniform or non-uniform, and may be optionally changeable by the user by the insertion of optional induction members in slots provided for this purpose, as discussed in Section A, Section D, and Figure 23.

Exemplary embodiments of this apparatus are:

a) A rotating doll, whose rotation speed can be user controlled, with multiple viewing positions (multiple cutouts). The doll can face more than one viewer, at different positions, for the maximum length of time.

b) A rotating doll, whose rotation speed can be user controlled, with programmably multiple viewing positions. This doll can face an arbitrary number of viewers, at different positions for the maximum length of time.

The resultant timed motion may be utilized for many purposes, exemplarily, production of musical notes by other apparatus (not shown) attached to doll apparatus. For example, music can be played by attaching a circular tuning fork with teeth to the axle, which periodically contacts a stationary hammer. A rotating switch on the axle can make lights

[redacted]

blink, etc. In general any timed waveform – electrical/mechanical/acoustic can be generated from the timed motion.

8. **Rotating Lollipop, whose speed can be controlled.**

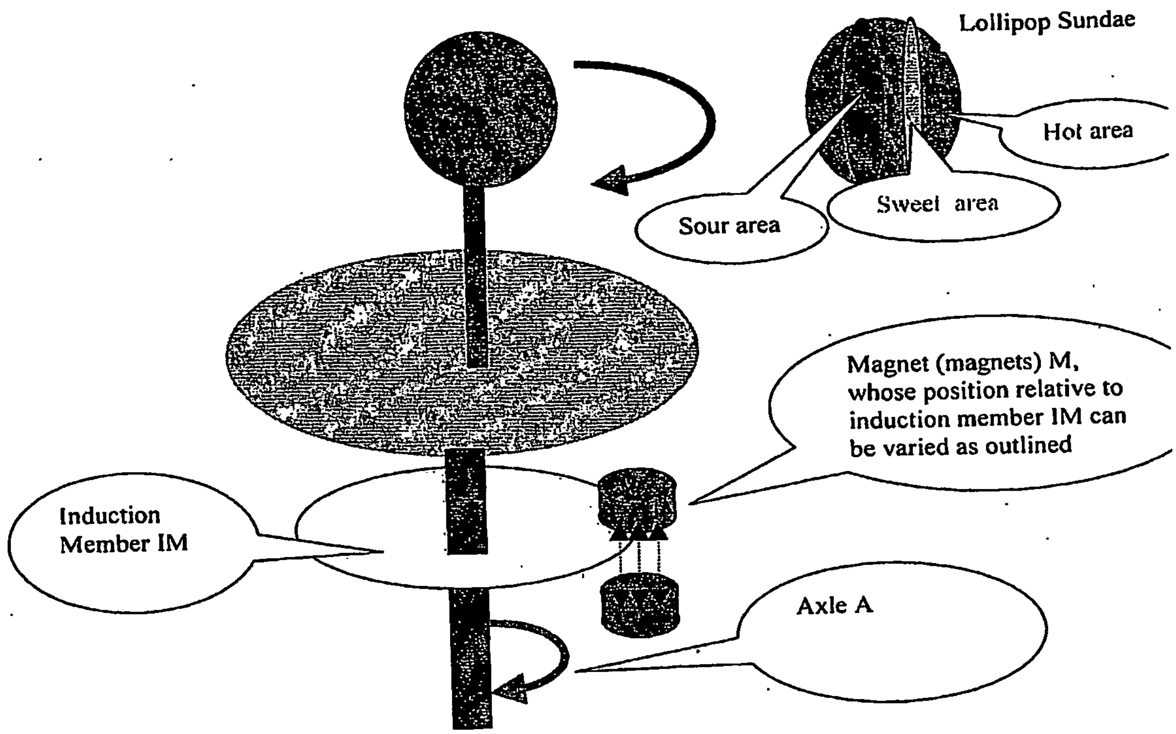


Figure 46 Rotating Lollipop with speed programmably controllable possibly in a non-uniform fashion,

Figure 46 shows a Lollipop that rotates at a speed which can be taster controlled, using controllable induction force. Use of multiple cutouts, in the induction member as discussed in Section A, Section D, and Figure 23, enables the speed of rotation to be varied in a single cycle for more variety.

Multi-taste "Lollipop Sundaes" can also be made and automatically tasted (sweet 50% of the time, sour 10%, hot 40% of time). The Lollipop may be different from the illustration, e.g. it can have an inner sweet core, surrounded by shells of sweet, sour and hot, etc. The speed of rotation will determine the speed of transitioning from hot to sweet, and the "dwell time" on any taste, thus adding more variety.

[redacted]

9. Magnetic CAM

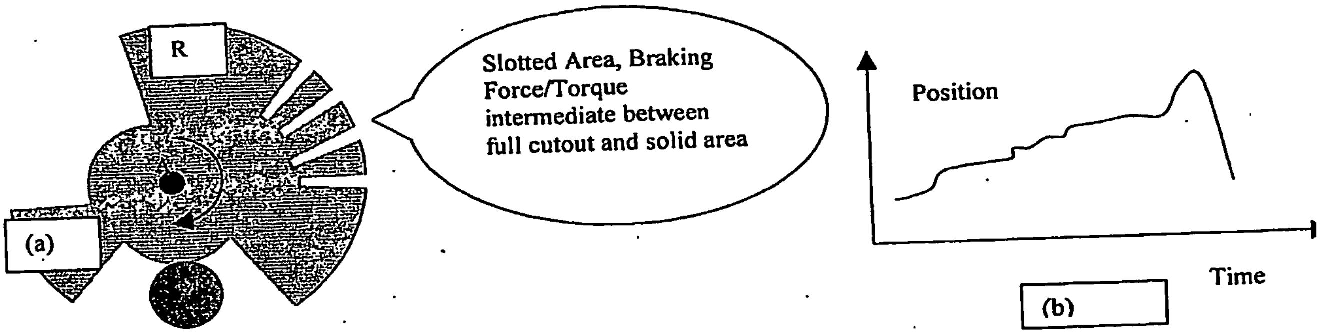


Figure 47: (a) Timing Control Induction Disk, used as a timing CAM (b) Angular Position as a function of time.

The timing control disk of Figure 22 can be alternatively regarded as a CAM, which generates any desired function of angular position of axle A over time Figure 47 (b), by appropriately controlling the induction forces/torques, as per Section A, B, C, D, and E. This creates a new apparatus, a CAM based on induction principles, whose timing profile can be designed to suit, possibly in a programmable fashion.

10. Toothbrush with Speed Control

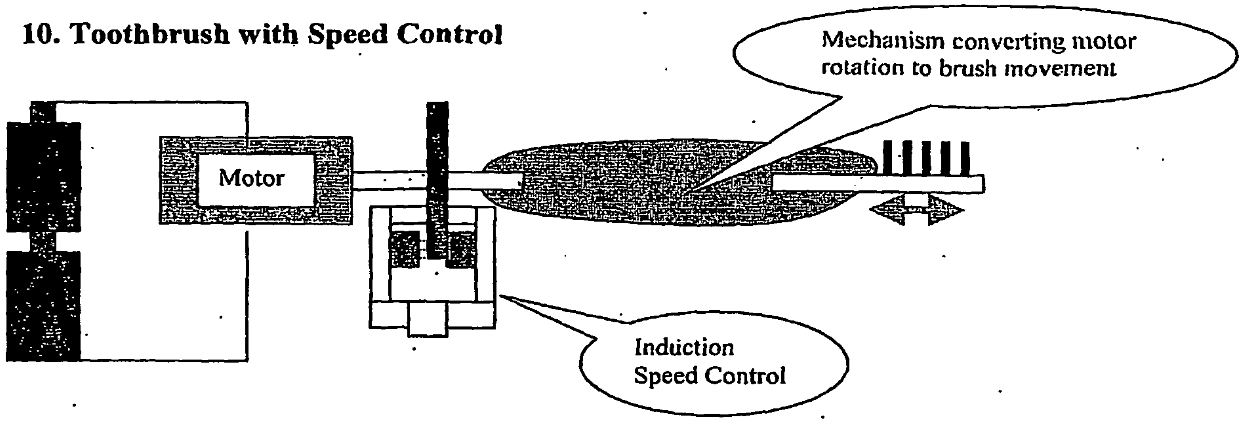


Figure 48 Powered Toothbrush with speed control using induction.

Figure 48 shows a powered toothbrush, exemplarily powered by 2 AA/AAA batteries. Motor (and hence brush head) speed can be controlled in a smooth and non-stick fashion, using the induction speed-control techniques outlined previously, in any of its variants (Sections A, B, C, D, and E). Various embodiments of this invention include the following.

(a) Using an induction disk, with magnets that can be moved axially or radially using mechanical means well known in the state of art. This enables the brush speed to be controlled for best brushing comfort.

(b) Using cutouts in the induction disk, which enables speed to be changed at different positions of the brush head, thus increasing brushing comfort even more. If the induction disk is connected to the drive shaft of the motor, the speed periodically varies with each motor revolution.

(c) Using induction members and magnets in the mechanism connecting the motor shaft to the brush head, which enables the speed of the brush head movement to be controlled in a possibly non-uniform fashion, for maximum comfort. Depending on the location of the magnets and induction members, the speed variation may be periodic with each motor revolution, periodic with each oscillation cycle of the brush head (typically lower), etc. The design of the magnets and induction members, for any desired speed variation of the brush head, is as per the discussion on general mechanisms in Section E (especially the reciprocating mechanism on page 46).

(d) Using programmable cutouts in the induction disk, or induction member (in the brush head mechanism), enables the user to customize the speed profile of his or her brush for maximum comfort.

(e) Use of Power Transmission Control, in the form of a eddy-current clutch enables the mechanism to smoothly disengage if the brush head encounters too much resistance in the mouth, enhancing safety.

(f) Use of a hysteresis member, or multiple autonomously magnetic interacting members, can allow rest-states of the toothbrush to be as desired. In one embodiment, the bristles can be magnetically "retracting" in a rest position for safety, and emerging only during brushing.

We reiterate that while we have shown a preferred embodiment, where the drive to the motor is directly from the battery, this is not necessary. The motor drive may itself be modulated by electronic techniques well known in the state of art (e.g. pulse width modulation), especially at higher voltages (e.g. 3-4 batteries).

11. Drawer with Induction Brake

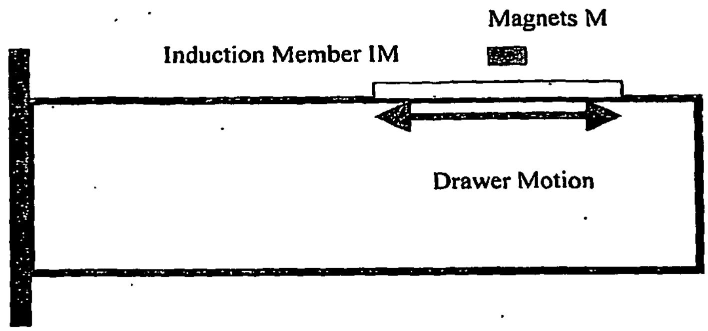


Figure 49 Drawer (Top View) with induction brake to prevent excessively violent opening/closing.

Figure 49 shows magnets M, inducing eddy-currents in induction member (a strip) IM, attached to the side of a drawer. The generated inductive force slows down drawer opening/closing, if excessively fast. There can be multiple induction members, on the side of the drawer, to generate retarding force at various desired drawer positions. For example, the drawer motion can be braked near the completely open and/or completely closed positions. Drawer opening/closing speed can be regulated using force control methods outlined previously (Sections A, D, and E). The stray magnetic fields generated can be reduced by magnetic shielding using back-iron etc., well known in the state of art[4].

12. Hinged Device

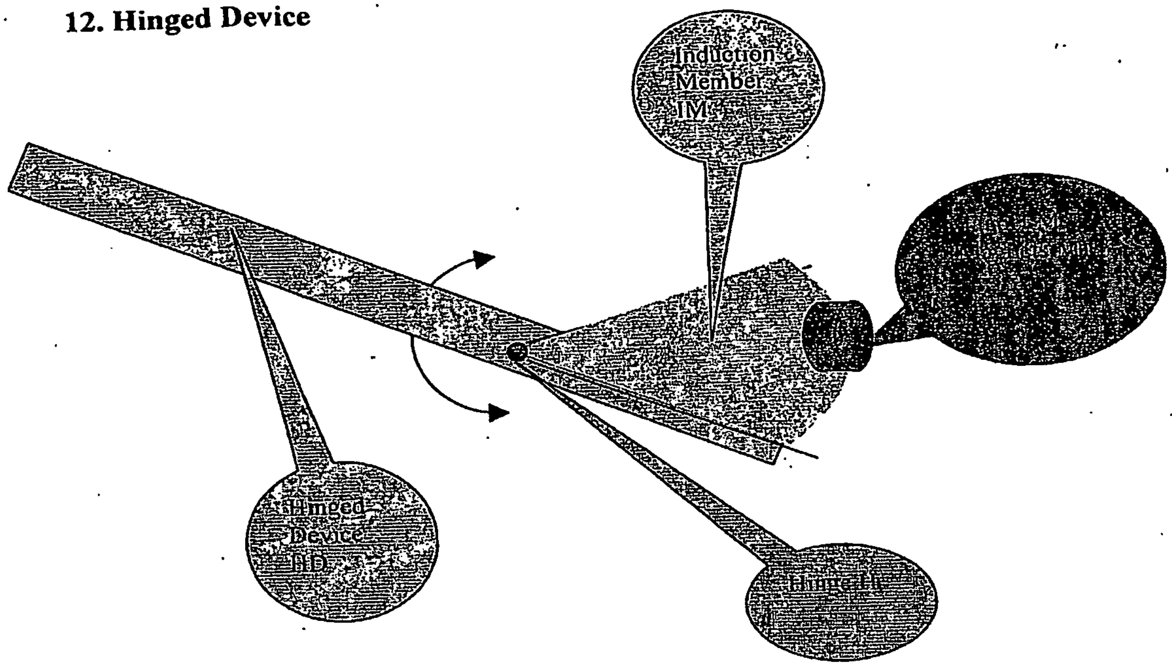


Figure 50: Apparatus using a hinge, enhanced to reduce excessively high-speed operation.

Figure 50 shows a hinged device HD being "braked" when induction member IM is near magnet (magnets) M. HD can exemplarily be

(a) A door

(b) An oven door

(c) A toilet seat

(d) A suitcase lid

(e) A lid for a plastic bin.

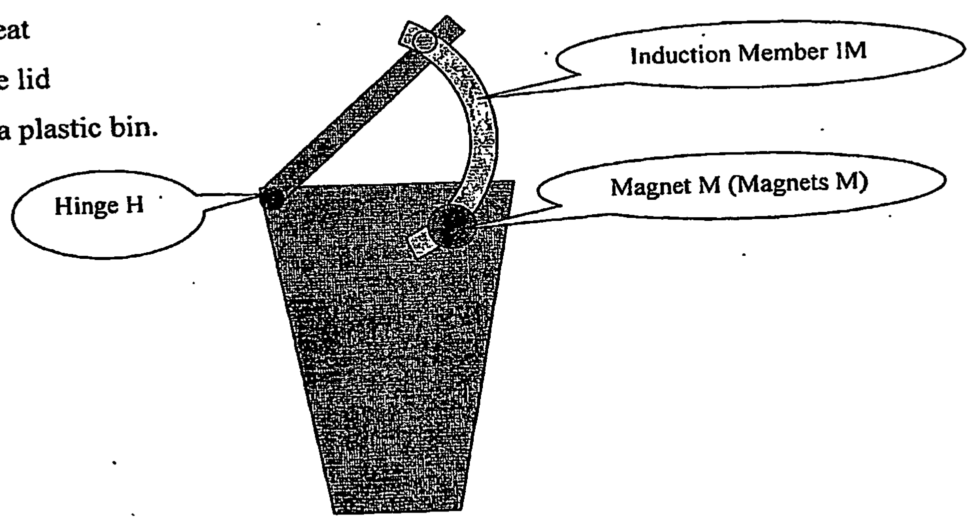


Figure 51: Induction Speed Limiting for bin lid. Induction Member positioned near edge of lid for maximum speed.

[redacted]

Additional mechanism may be present to transmit the hinged device HD's motion to the induction member. For example, a long lever arm may be used to give a higher speed to the induction member, and hence higher force/torque (e.g. the bin lid in Figure 51). The force/torque can be non-uniform, following any of the techniques described previously (Sections A, D, and E).

13. ADJUSTABLE HEIGHT/ANGULAR POSITION PEDESTAL FOR FLOWER POTS, AND OTHER OBJECTS

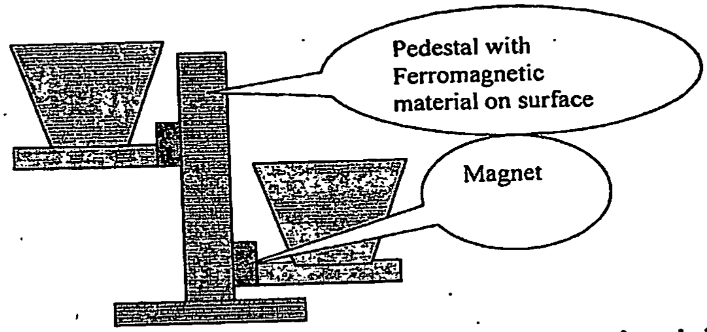


Figure 52: Magnetically Adjustable Pedestal, showing two pot platforms, whose height/angular position can be adjusted

This is an example where undesirable motion has to be prevented. Figure 52 shows a pedestal, with a ferromagnetic material on its surface (e.g. iron plate), with magnetically attached platforms (with magnets and flux return paths), whose height can be varied anywhere on the pedestal. Pots/Other objects can be placed on the platforms, and the heights varied as desired. Magnetic field modulation techniques as per Section A, where pole pieces can be inserted, the magnetic flux return path changed, etc., can be used to quickly attach and/or release the magnetic platforms from the pedestal. To increase holding force, the magnets may have both north and south poles contacting the ferromagnetic pedestal surface.

Stability of attachment can be provided in several ways. Mechanical guides/slots can be provided to prevent the pots from tipping over sideways, and also provide additional support to prevent the magnets from coming loose from the pedestal. In another embodiment, the surface of both the pedestal and the magnets can have matching grooves, projections, or general texture. For example, the surface of the pedestal can have shallow grooves, into which small projections from the magnet surfaces fit snugly (Figure 53).

In addition to height, the angular position of the platforms can be adjusted if

1. A cylindrical ferromagnetic pedestal is used (e.g. a steel pipe).
2. Magnets and flux return paths having a cylindrical surface exactly matched to the pedestal (including any grooves/projections/texture) are used.

[redacted]

The same idea can be embodied in a spherical pedestal, with ferromagnetic material possibly with grooves/projection/texture on the surface, providing attachment to platforms/clips, which have magnetic attachments to the surface. The surfaces of the magnets will have projections/grooves/texture matched to those of the spherical pedestal. In general a pedestal having any desired surface contour can be used, together with matching magnets.

Since the platforms are detachable, means of minimizing field leakage when the platforms are not attached can be used, and can consist simply of ferromagnetic covers, matched to the surface of the magnets.

Alternative embodiments of the same idea, include a showerhead whose height/angular position can be adjusted, a tap whose height/angular position can be adjusted, etc. In general, a support with an arbitrary surface contour, capable of firmly gripping an object at a continuously adjustable height/angle/position can be created, using such "textured" magnets.

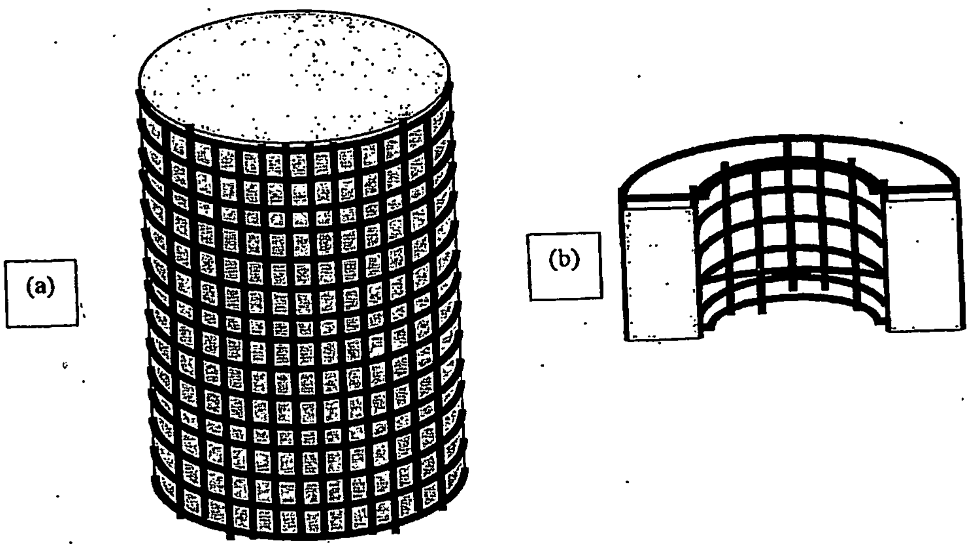


Figure 53 (a) Ferromagnetic Grooved pedestal, and (b) Matching projections on magnet/magnets attaching the platform(s) to the pedestal. The matched grooves and projections enhance holding force, and prevent motion in any direction. The ferromagnetic pedestal can be spherical, or any other shape, with grooves on its surface. Magnet/magnets holding the platforms to the pedestal, have matching projections on their surface.

14. Magnet Wiring Clip

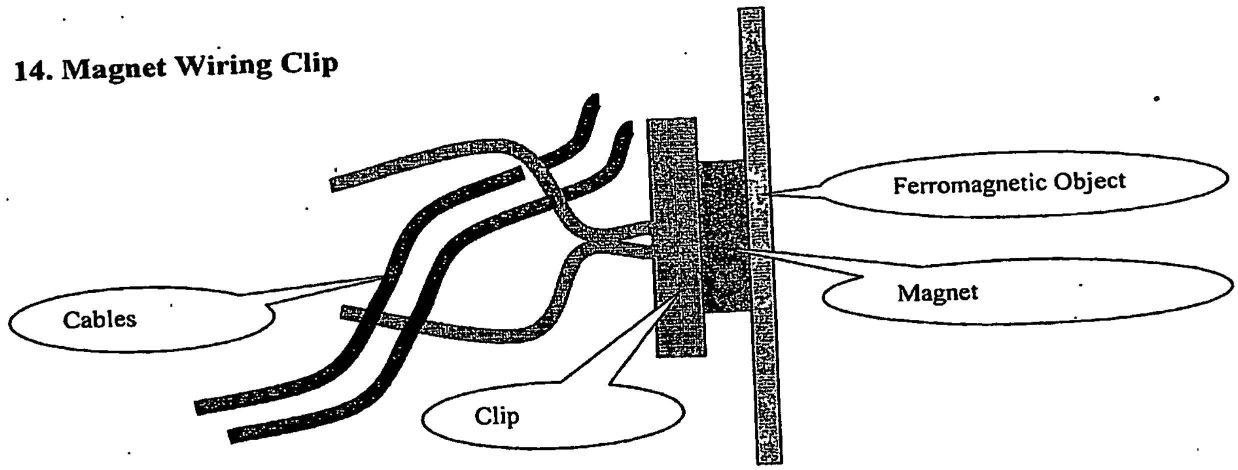


Figure 54: Magnetic Cabling Clip holding cables to ferromagnetic object (e.g. computer cover).

We show a magnetic clip for routing cabling, which has a clip, and a magnetic base to hold the cables at any desired position in proximity with any object (e.g. shelf) that is ferromagnetic. Exemplarily, the clips may be attached to the sides of computers, at any desired positions, and the computer cables conveniently routed.

[redacted]

Abstract

The objective of the present invention is to extend the domain of motor speed (and general motion) control, traditionally characterized by electronic techniques, to small apparatus like bubble vibration toys, paper dispensers, well pulleys, toothbrushes, display turntables, rotating lollipops, very low cost timing CAMs, toy racing cars, drawers, hinged objects, disk drives, etc. These apparatus are either unpowered (i.e. human powered), or typically run on one or two AA/AAA batteries, generating a maximum of 3V initially, and less after a little use. This voltage is too low for cost-effective electronic control. The object of the present invention is to present techniques that enable this to be done, at very low cost. The present invention achieves this by changing the power input to the apparatus, the power transmitted through various portions of the apparatus, or the load offered to the apparatus, using interactions of magnetic fields and induction/hysteresis members of various geometry, dimensions, and properties, possibly changeable during use. In addition to all this, we describe new apparatus resulting from the application of our invention to existing apparatus.

While the invention is primarily targeted at low cost mass-market apparatus, this does not limit its use in other contexts, e.g. in high reliability apparatus due to simplicity of design, very high performance apparatus using closed loop controls by reducing the open-loop deviations of apparatus from the desired goal, etc.

[redacted]

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Pages 93 to 98 are intentionally omitted.

G N. Srinivasa Prasanna
April 10'2003

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